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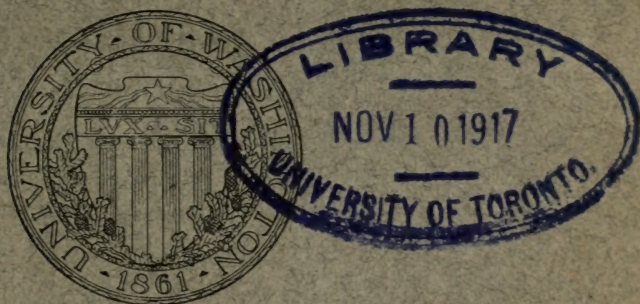
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UNIVERSITY OF WASHINGTON
BUREAU OF INDUSTRIAL RESEARCH

H. K. BENSON, Director

Eng. Exp. Sta. Series.

BULLETIN No. 1

Creosoted Wood Stave Pipe and
Its Effect Upon Water for Domestic and
Irrigation Uses



PREPARED UNDER A COOPERATIVE AGREEMENT BETWEEN THE
BUREAU OF INDUSTRIAL RESEARCH, THE FOREST PRODUCTS
LABORATORY OF THE UNIVERSITY OF WASHINGTON, THE
WEST COAST LUMBERMEN'S ASSOCIATION, THE ASSOCIATION
OF CREOSOTING COMPANIES OF THE PACIFIC COAST, THE
WATER AND ENGINEERING DEPARTMENTS OF THE CITY OF
SEATTLE, THE PACIFIC COAST PIPE COMPANY AND THE
PACIFIC CREOSOTING COMPANY.

PUBLISHED BY THE UNIVERSITY
SEATTLE.
1917

THE Bureau of Industrial Research of the University of Washington was established, January 21, 1916. Its functions are: (1)

The co-ordination of the several departments within the University that possess expert knowledge of a given problem; (2) the study of industrial problems which have a general part in the up-building of the State, and (3) the undertaking of investigations of primary interest to the individual or corporation proposing them. The work of the Bureau is controlled by the President of the University and a faculty staff selected to take charge of the various problems under investigation. Communications to the Bureau should be addressed to the Director, H. K. Benson, University of Washington, Seattle, Wash.

CREOSOTED WOOD STAVE PIPE AND ITS EFFECT UPON WATER FOR DOMESTIC AND IRRIGATION PURPOSES

A SUMMARY OF TESTS CONDUCTED BY THE
UNIVERSITY OF WASHINGTON
BUREAU OF INDUSTRIAL RESEARCH

H. K. Benson,
Director.

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CREOSOTED WOOD STAVE PIPE AND ITS EFFECT UPON WATER FOR DOMESTIC AND IRRIGATION USES.

INTRODUCTION.

THOUGH untreated Douglas fir wood stave pipe normally has a very long life when properly installed, the use of untreated pipe in irrigation lines where the pipe is periodically empty is not conducive to long service, for the conditions for decay may often under such circumstances be at an optimum. As wood stave pipe has the undeniably great advantages of low initial cost, ease of installation and proportionately greater carrying capacity than other usual forms of pipe it is used very extensively, but lately a demand for some method of protecting the pipe from decay under the severe conditions encountered in irrigation service has arisen. Experiments have therefore been made by private companies to determine the effect of creosoting upon the quality of the water passing through wood stave pipe. It is generally recognized that properly creosoted material remains immune from decay for considerable periods of time, and as the experiments mentioned above indicated that creosoting did not impart an offensive taste to the water, it has been asserted that creosoted wood stave pipe lines can be used with highly superior results.

In the spring of 1916, the city of Seattle was urged to use creosoted wood staves in the reconstruction of the main water supply lines of its water system. As no really authoritative experiments had been made to determine the practicability of such use, an appeal was made to the Bureau of Industrial Research to take up the problem and to determine by a series of tests just what effect the creosoting of wood stave pipe under such conditions would have upon the potability of the water passing through the pipe. With the cooperation of the parties most directly concerned with the problem the experiments described in the following report were accordingly carried out. The taste of the water was accepted as evidence of its potability, as the slight amount of creosote in water that had a very pronounced taste of creosote would not be sufficient in quantity to produce the slightest physiological effect on the users of such water.

The test was extended to determine the effect of minute quantities of creosote upon the availability of the water in irrigation.

METHOD OF TESTING.

Apparatus. The apparatus used in this experiment consisted of 48 feet of four-inch creosoted Douglas fir wood stave pipe, treated as described below, a round Douglas fir stave tank 3 feet in diameter and 9 feet deep, a 2½-inch rotary circulating pump, electrically driven, and various galvanized iron connecting pipes, valves and other minor fittings.

Treatment of Pipe. The staves for the pipe were treated on September 16, 1916, in the experimental plant of the Pacific Creosoting Company at Creosote, Washington. The treatment of the staves was conducted under the supervision of a member of the Bureau Staff. The material used in the experimental pipe consisted of twenty-five staves of the following description:

Douglas Fir Staves, Dressed Before Treatment.

Length, feet	Number	Lineal feet	Cubic feet	Weight, pounds
10	25	250	5.45	203

In the same charge with these staves were included 12.5 cubic feet of undressed stave lumber * weighing 512 pounds. This was included as the Bureau intended to conduct a test on pipe manufactured from material treated "in the rough" and dressed after treatment, in addition to that manufactured from the staves which were dressed before treatment. The use of the pipe manufactured from this material was however found to be impracticable. The volumes listed above are based on the actual dimensions of the material, and the weights were obtained by careful weighing immediately before treatment. All of the material had been thoroughly kiln dried. The amount of oil required for the specified treatment was computed on the basis of a charge consisting of 18 cubic feet.

The treatment given the above material was briefly as follows:

The charge was boiled under a vacuum for four hours. The required amount of oil increased by a factor of 1.4 to allow for the rebound was then injected, the pressure period extending over a period of 45 minutes. Pressure was then released and followed by an expansion bath extending over a period of three hours. The oil was then removed and a vacuum maintained within the retort for fifteen minutes. The temperature during the boiling under a vacuum varied between

* The stave lumber was of the following description:

Length, feet	Number	Lineal feet	Cubic feet	Weight, pounds
7	10	70		
10	5	50		
9	20	180		
		TOTAL 300	12.5	512

192 and 195 degrees F.; during the pressure period, between 190 and 178 degrees F. During the expansion bath the temperature was maintained between 228 and 231 degrees F. The charts included in this report, Figures 1 and 2, illustrate graphically the manner of treatment.

After treatment the dressed staves were found to weigh 292 pounds, indicating a treatment of 16 pounds of creosote per cubic foot of wood. The rough staves, which were not used in the subsequent experiments, were found to weigh 608 pounds, indicating a treatment of $7\frac{1}{2}$ pounds of creosote per cubic foot of wood.

Conduction of Experiment. The equipment and operation of this experiment was such as to make it representative as nearly as possible of conditions existing in a 56-inch creosoted wood stave pipe line carrying water from Landsberg intake, on Cedar River, to the Volunteer Park reservoir in the city of Seattle. Since the length of such a pipe line would be approximately $22\frac{1}{2}$ miles, or 118,600 feet, water flowing at a velocity of 5 feet per second would be in contact with the inner surface of the pipe for approximately 6 hours. In this experiment water was therefore circulated through the pipe for 6 hours at a velocity of 5 feet per second before taking each sample and renewing the volume of water in the pipe.

As the ratio of the inner area to the volume is fourteen times as great in a 4-inch pipe as in a 56-inch pipe of equal length, a tank containing a volume of water equal to fourteen times the capacity of the pipe was connected to the intake and discharge ends of the pipe. Since the inner surface of this tank had no action on the water contained in it, the ratio of the total inner surface of the creosoted wood stave pipe used in the experiment to the total volume of water circulated through it was the same as the ratio between the total inner surface of a 56-inch pipe line $22\frac{1}{2}$ miles long and the total volume of water in such a pipe line. Therefore, since the ratio between the creosoted surface and the quantity of water was the same, the velocity of the flowing water was the same and the water was in contact with the creosoted surface for the same length of time, conditions in this experiment were considered to be thoroughly representative of those existing in a 56-inch creosoted wood stave pipe line conveying water from the Landsberg intake on Cedar River to the Volunteer Park reservoir in the city of Seattle.

Equipment Used. Illustrations 3 and 4 show general views of the pipe, storage tank and pump from two opposite directions. As shown in the photographs, the 48 feet of creosoted wood stave pipe was laid in the form of a letter U in the bottom of a concrete canal about 4 feet deep and 4 feet wide. The intake end of the pipe was fitted into

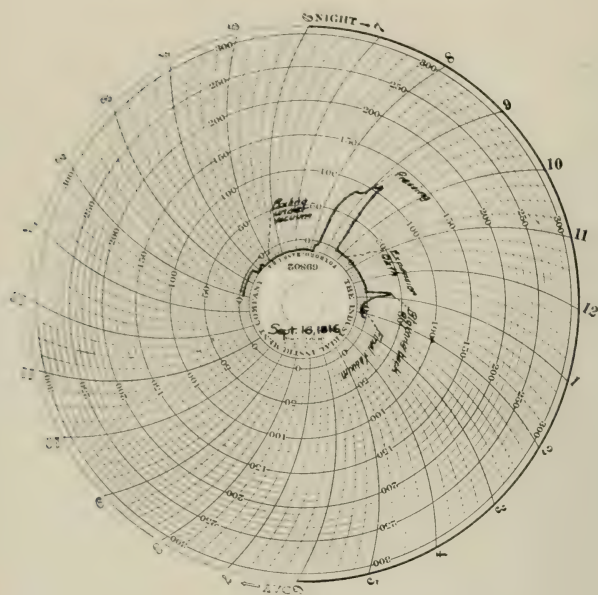


Fig. 1.

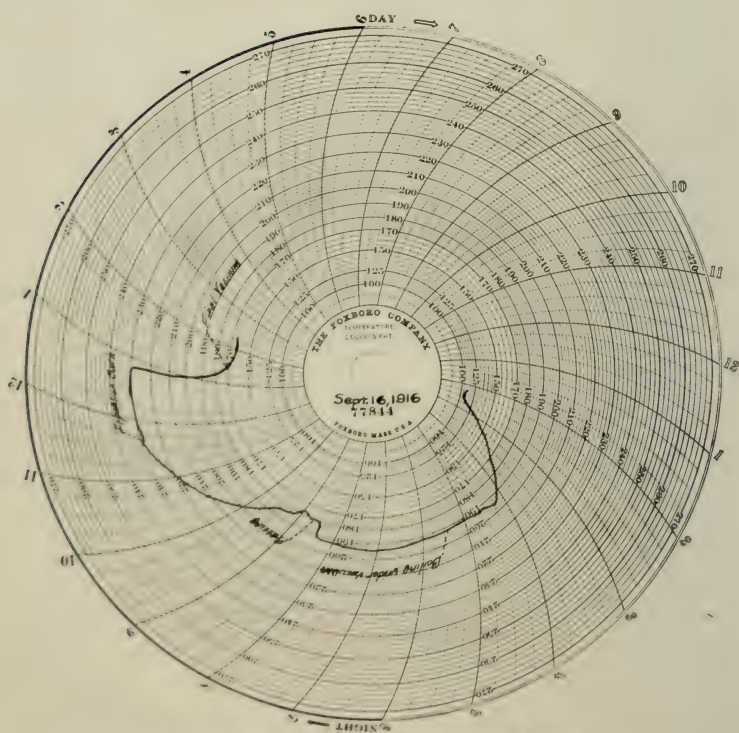


Fig. 2. Record of Creosote Treatment of Staves.

the side of the tank about 4 inches from the bottom. The circulating pump drew water from the other end of the pipe through a short section of galvanized iron pipe, and discharged it below the surface of the water in the storage tank through another section of galvanized iron pipe. The depth of water in the tank was kept at 8 feet and 3 inches so that the volume of water in the tank remained equal to fourteen times that in the pipe. The head of water in the center of the pipe was therefore 7 feet and 9 inches, sufficient to overcome any tendency for a negative head to occur in the pipe or pump.

The velocity of the water in the wood pipe, as computed from the time necessary to discharge the entire tank full of water, was 4.6 feet per second.* Very little variation in velocity during the test could take place, as the motor maintained a constant speed and the pump was of the positive displacement type. The top of the storage tank was tightly boarded over and covered with roofing paper. An air tight joint was made between the staves and the cover by inserting a layer of roofing felt between the staves and the cover before nailing the latter down. Every precaution was taken to avoid any possible aerating effect through the discharge of the water into the tank or during its period of standing in the tank.

The wood pipe was partly or entirely submerged in water during the entire test. During the last days of the test the pipe was completely covered by water. The system was emptied by uncoupling the discharge pipe from the pump and pumping the water out of the tank and pipe. During the first two weeks of the test the temperature of the water in which the pipe was partially immersed was very near the freezing point. Later the temperature rose somewhat, probably averaging 40 deg. F.

Operation. The tank was filled with water and allowed to soak for eight days before it was connected with the pipe, to rid the tank of the woody taste that new tanks impart to water. However, in some of the first samples taken during the test, a decided woody taste was noticed. The test began on November 12 and ran continuously except for two twenty-hour periods** until it was completed on December 13. During the first nine days of the test the tank and pipe were emptied three times a day; at 6 A. M., 12 M. and 6 P. M. During the following eleven days they were emptied at 12 M. and 6 P. M. only.

* As this water was discharged against an increasing head as the water in the tank lowered, this figure for velocity is slightly lower than the velocity actually existing during the operation of the experiment.

** The pipe was empty from 5 P. M., on November 12, to 6 P. M., on November 13, and from 12 P. M., on November 22, to 12 P. M., on November 23. During part of this period the pipe and tank were filled with mud and water due to the accidental bursting of a water supply main in the near vicinity.

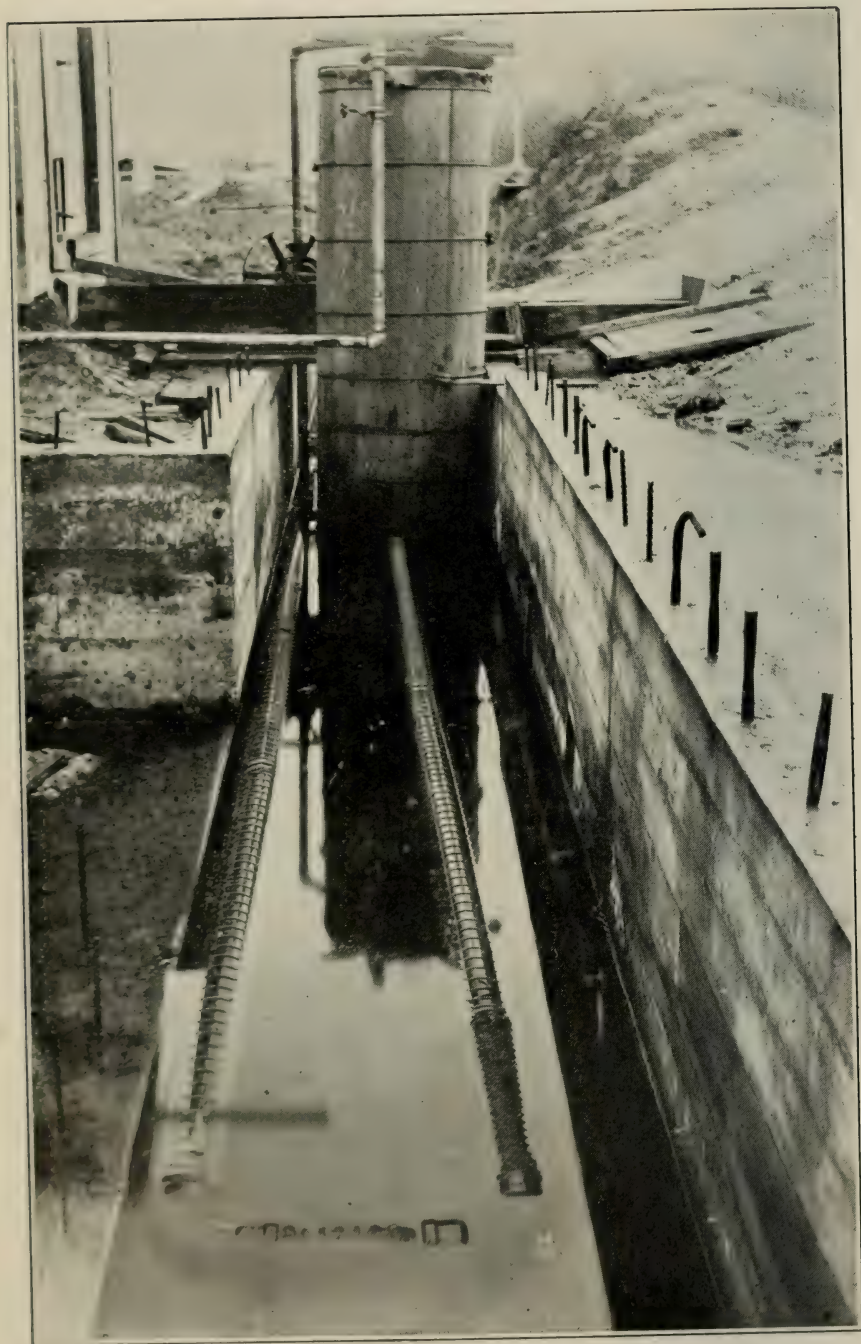


Fig. 3. Apparatus Used In Test.

During the last nine days of the test the volume of water in the pipe and tank was changed only at 12 M., with two exceptions when samples were desired. It is apparent therefore that one volume of water was circulated through the system for twelve, eighteen and sometimes twenty-four hours instead of six hours as it should theoretically have been. However, as this water was not used in the samples tested and as the amount of creosote absorbed by the water in any case was infinitely small, this fact was not considered as having any appreciable bearing upon the accuracy of the test. Any possible error worked to the disadvantage of the pipe under test.

Samples were taken at the end of each six hour run. Two liter glass bottles with ground-in glass stoppers were used. The samples were stored in a cool place until they were tested.

Testing of Samples. The Bureau Staff met five times while the experiment was in progress and tested various samples of the water taken in the manner previously described. Undiluted samples and various dilutions of the samples were tasted. The object in diluting the samples was to duplicate actual conditions that would exist in the Cedar River supply with one creosoted 56-inch line which had been in service for the same length of time as the pipe in this experiment carrying from one-half to one-third of the total water supply. The reports on the various samples are as follows:

Sample taken after the pipe had been in continuous service for 168 hours, or 7 days: Tested on November 20, by four members of the Bureau Staff and two representatives of the City of Seattle Engineering and Water departments. All reported that a noticeable taste of both creosote and wood was present in the sample.

Sample taken after 312 hours, or 13 days: Tested on November 27 by seven members of the Bureau Staff. All reported that the undiluted sample had a slight taste of creosote, while no appreciable taste was present in a sample diluted with two volumes of tap water.

Sample taken after 561 hours, or approximately 10 days: Tested on December 4, by six members of the Bureau Staff and two representatives from the City of Seattle Engineering and Water departments. Two of those present reported that the undiluted sample had a slight taste of creosote, while six could detect no trace of creosote.

Sample taken after 26 days: Tested on December 11, by four members of the Bureau Staff. Two members of the staff could detect no foreign taste, while two noticed a slight taste, as though the water had been boiled for a short period.

Sample taken after 20 days: Tested on December 14, by three

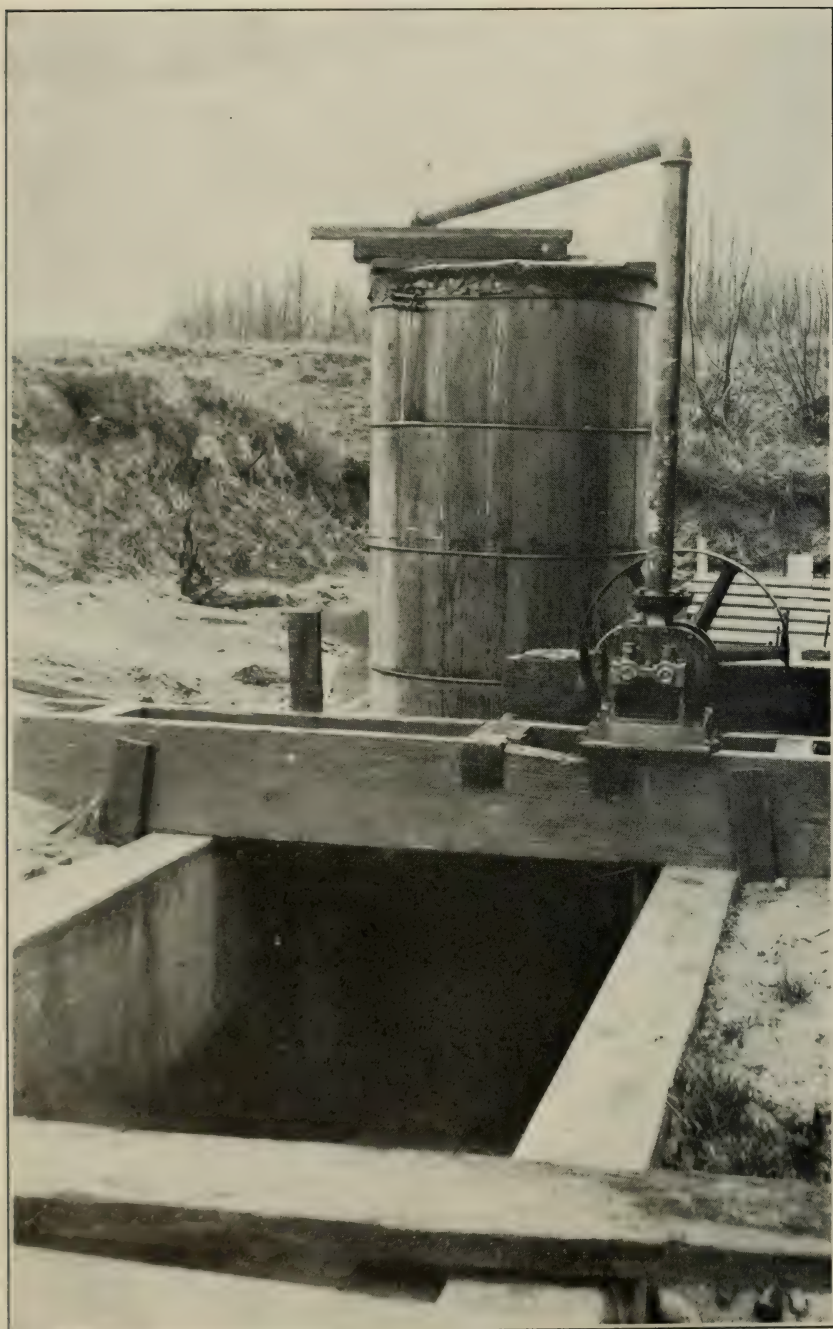


Fig. 4. Apparatus Used In Test.

members of the Bureau Staff and two representatives from the City of Seattle Engineering and Water departments, who met at the University of Washington Faculty Men's Club for lunch. Water from this sample was used in making tea, and portions diluted with two parts of ordinary city water were used for drinking. No foreign taste was reported by those present. Undiluted portions of this sample were tasted by several members of the faculty of the university who were not aware of the nature of the test or where the sample was obtained. None reported the presence of any peculiar taste. Several specimens from this sample were submitted to the Home Economics department of the University to be tested in one of the classes of dietetics. None of the young women tasting the water knew where or how the sample was obtained. The reports received from the class show practically no difference between an undiluted sample taken after the pipe had been in service for 29 days and a sample taken from ordinary city water.

AVAILABILITY OF CREOSOTED WOOD STAVE PIPE LINES IN IRRIGATION PROJECTS.

Although the main problem in this investigation was to determine what effect creosoted wood stave pipe lines would have upon drinking water, the Bureau Staff felt that it would also be wise to determine what effect small amounts of creosote in the water would have upon crop plants if used for irrigation. The experiments on this phase of the problem may be arranged under three different headings: 1. The effect upon growing plants. 2. The effect upon the germination of seeds. 3. The effect upon plants grown in water cultures.

The water used in the following experiments was obtained from an experimental pipe line other than the one used in the experiments previously described in this report. A short description of this pipe line therefore follows:

Treatment of Pipe. The staves used in this pipe were thoroughly kiln dried before treatment. They were treated by the Pacific Creosoting Company with a commercial charge of lumber. Due to the fact that the staves were so much drier than the lumber, they absorbed an undue portion of the creosote oil. The staves were accurately weighed immediately before treatment and again after the charge was withdrawn, and they were also carefully measured to determine their exact volume. From this data the absorption of the oil was determined to be 24 pounds per cubic foot, far in excess of the treatment desired.

Operation of Pipe Line. The pipe was laid on the surface of the

ground, exposed to the sun's heat every day until about noon. As the test was conducted during the summer, the temperature of the pipe and the water contained in it was very high. The pipe was filled with water, which was allowed to remain in a stagnant condition for six hours, when a sample was taken and the pipe emptied.

Effect of the Test Water on Growing Plants. Several flats were prepared and kept in a green-house where the water supply could be definitely controlled. In these the following seeds were sown: alsike clover, white clover, common millet, corn and wheat. The flats thus prepared were watered every day with water that was obtained twenty-four hours after the creosoted pipe had been placed in service. As a control, other flats were prepared in exactly the same manner with the same kind of soil, the same kind and approximately the same number of seeds, and these were watered with tap water instead of water obtained from the creosoted pipe. These two series were kept under observation for about three months, at the end of which time no difference could be distinguished between the plants watered with the test water and the controls, either as to time of germination, the percentage of germination, the rapidity of growth or the general vigor of the plants. Figure 5 is a photograph of these plots at the end of four weeks. The plants in row No. 1 are the controls, watered with tap water, while those in row No. 2 were watered with water from the creosoted pipe line.

A further test was made by planting alsike clover, white clover and wheat in large galvanized iron cans eleven inches in diameter and fourteen inches deep. These and the three controls were kept in the laboratory and treated in the same manner as the flats in the green-house with very comparable results. Figure 6 shows a photograph of the wheat, (A) treated with the test water, (B) treated with tap water.

The Effect of the Test Water on Germination. In order to determine the effect of this water on the germination of seeds, tests were made by placing the seeds between moist pieces of filter paper. These were placed in common soup plates and covered with glass sheets. One set was moistened with water from the creosoted pipe line, while the other was treated with ordinary tap water. The following seeds were tested: wheat, corn, peas, beans, white clover, alsike clover, common millet, and timothy. No difference could be detected in the percentage of seeds germinating in the two series of plates.

The Effect of the Test Water on Water Cultures. Seeds of corn, beans and peas were sprouted in moist sawdust, and when the seed-

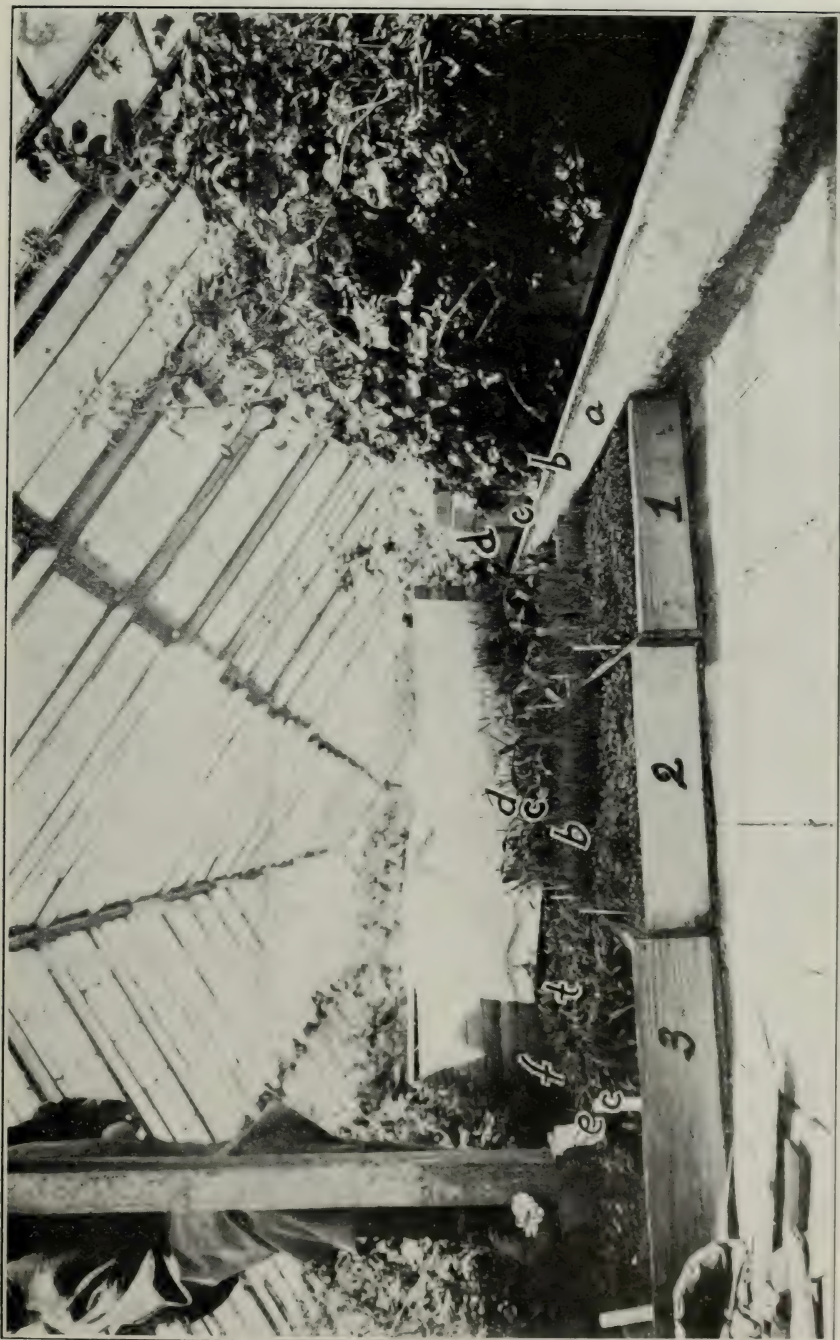


FIG. 3. Plants Treated With Water From Creosoted Pipe and the Controls. Plants In Row 1, Are the Controls, Row 2 Have Been Treated With Test Water; 1a and 2a Are Alsike Clover; 1b and 2b, Timothy; 1c and 2c, Corn; 1d and 2d, Wheat; 1e and 2e, Millet, 3f Being the Control.

lings were about two to three inches long, five of each kind were transferred to as many four-ounce bottles containing the following nutrient culture medium prepared with water taken from the creosoted pipe:

- 12 grams calcium nitrate
- 3 grams potassium nitrate
- 3 grams magnesium sulphate
- 3 grams neutral potassium phosphate
- 3 grams sodium chloride
- 1,200 cc. water from the creosoted pipe.

As a control a similar culture medium was prepared with tap water, and an equal number of seedlings were placed in four-ounce bottles containing this medium. The medium described above was used because it has been found possible to grow plants to maturity in it, when so desired. The two series were compared daily. No difference could be detected between them.

One of the most delicate tests for toxic material in water is the effect of such material on the development of root hairs. Dr. Rigg has shown that ordinary bog water obtained in the vicinity of Seattle is toxic to the root hairs of the common house plant known as the Wandering Jew, or *Tradescantia*. When cuttings from this plant are placed in bog water, the growth of the root hairs is either completely inhibited or at least stunted. He has further shown that the toxicity of the water disappears shortly after the water is removed from the bog; that is, it requires only a very slight dilution to remove this toxic condition.

Following this suggestion water cultures were made of cuttings of *Tradescantia*, using water from the creosoted pipe, distilled water and ordinary tap water. The first sample of water from the creosoted pipe was taken twenty-four hours after the experiment was begun, and samples were then taken every two or three days for about four weeks. A series of cultures was made with the different samples from the creosoted pipe, and controls as described above. In the first few samples the growth of root hairs was completely inhibited by the presence of the creosote. In samples obtained after the pipe had been in service for three weeks, stunted root hairs developed.

When properly creosoted pipe became available this experiment was repeated. Root hairs developed as readily and normally in the water obtained from this creosoted pipe as in tap water and distilled water, and in some cases even better than in water obtained from

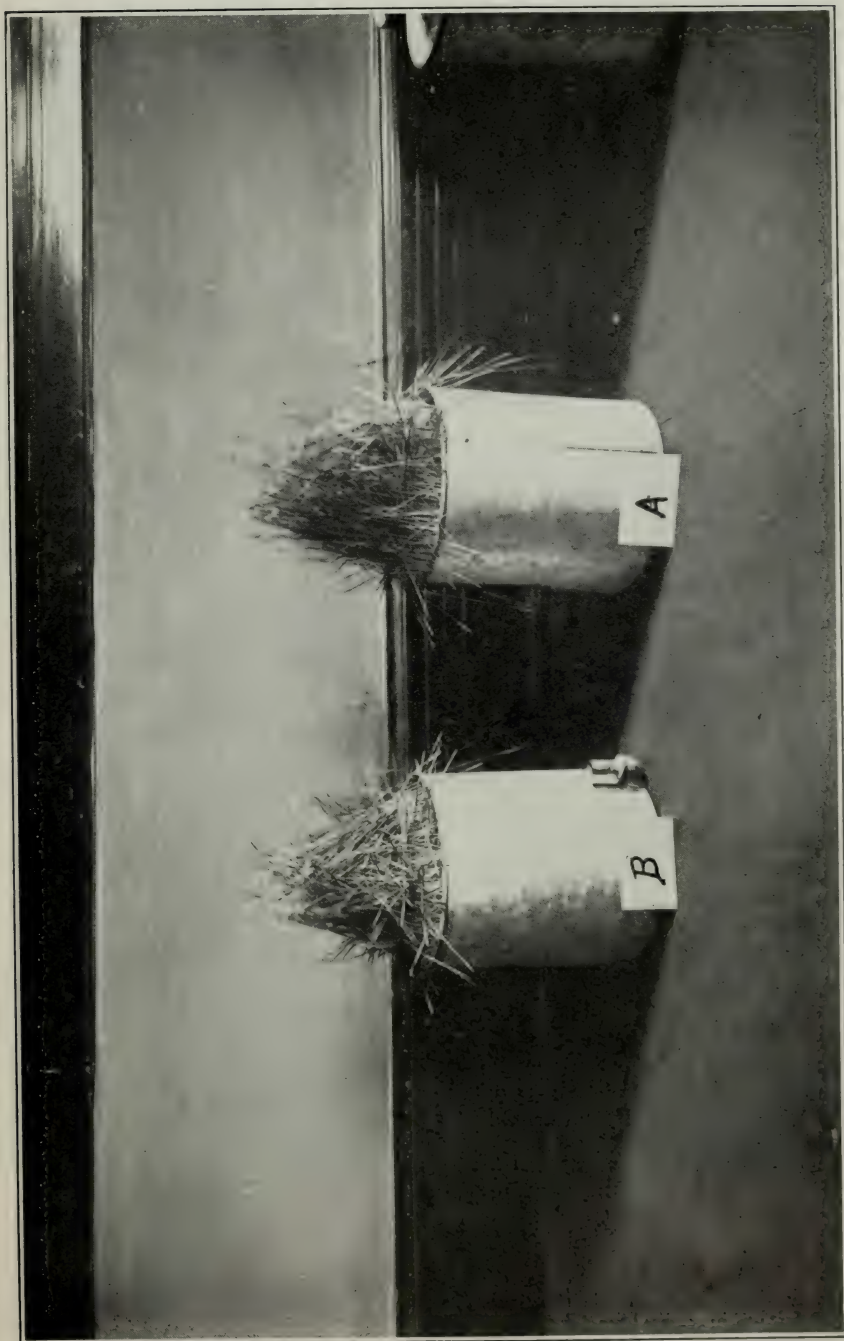


Fig. 6. Wheat; A, Supplied With Water From Creosoted Pipe; B, With Tap Water.

Lake Washington. Root hairs began to develop in samples of water taken from the creosoted pipe line twenty-four hours after the test was begun.

CONCLUSIONS OF THE BUREAU STAFF

1. As previously stated, conditions in this experiment are considered to be thoroughly representative of those existing in a 56-inch creosoted wood stave pipe line conveying water from the Landsberg intake on Cedar River to the Volunteer Park receiving reservoir in the City of Seattle.

2. After the experimental pipe line had been in service for thirteen days, no taste of creosote could be detected in a sample of the water diluted with two parts of ordinary city water.

3. After the experimental pipe line had been in service for twenty-nine days, no taste of creosote could be detected in undiluted water flowing through it.

4. The amount of creosote that diffuses into water in ordinary creosoted pipes does not have an appreciable injurious effect upon plants either in the time of germination, the percentage of germination, the rapidity of growth or the general vigor of the plant.

SUPPLEMENTAL REPORT ON THE CREOSOTED WOOD STAVE LINE OF THE WENATCHEE RECLAMATION DISTRICT.

While the investigations of the Bureau of Industrial Research were under way, a creosoted wood stave pipe line was installed in the irrigation system of the Wenatchee Reclamation District, a short distance from Wenatchee, Washington. This line is designed to carry water for domestic use as well as for irrigation. It has a total length of 8,947 feet, and includes 5,675 lineal feet of 63-inch creosoted pipe, 2,470 lineal feet of 60-inch creosoted pipe and 802 lineal feet of 44-inch untreated pipe. It was constructed during the past winter and water was first admitted at 5:00 p. m. on April 16, 1917. The pipe was designed and erected by Mr. Marvin Chase, Consulting Engineer, and Mr. C. C. Williams, District Engineer. It operates under a head varying from zero feet to 172 feet in the creosoted sections. Water is carried in the 63-inch section at the rate of 2.31 feet per second and 2.55 feet per second in the 60-inch section, and under normal operation it delivers 50 second feet. The accompanying illustrations, Figures 7 and 8, give some idea of the magnitude of this project.

As a check upon the experiments carried out on the University of Washington campus, the Bureau Staff included the Wenatchee pipe



Fig. 7. Intake of Wenatchee Pipe Line.

line in its investigation. A member of the Staff made a trip to Wenatchee and made a thorough inspection of the pipe line. At the time of his visit the water had been passing through the pipe for five days. Resident users of the water were asked for their opinions upon the quality of the water, and in all cases they reported that after the second or third day of use there was no taste of creosote in the water after it had passed through the creosoted pipe line.

Samples of the water after passing through the Wenatchee pipe line were collected and tested by the Bureau Staff. The water had been running through the pipe for eleven days when these samples were taken. The most critical examination failed to show the presence of any foreign taste in the water resulting from the use of creosoted wood staves in the construction of the pipe line. The results of this examination, therefore, tend to strongly corroborate the previous conclusions of the Bureau Staff.

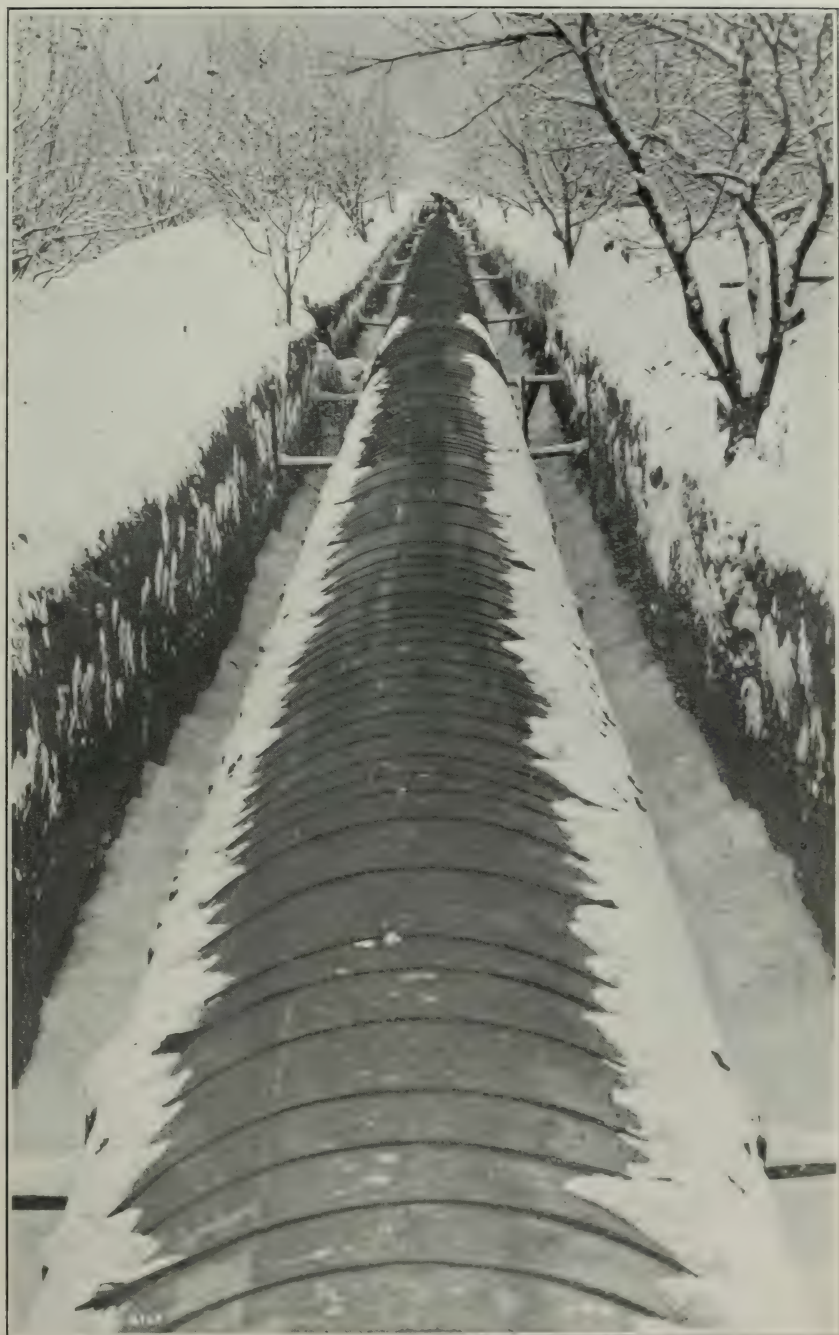


Fig. 8. Short Section of Wenatchee Pipe Line Before Backfilling

UNIVERSITY OF WASHINGTON
BUREAU OF INDUSTRIAL RESEARCH
H. K. BENSON, Director

Eng. Exp. Sta. Series

BULLETIN NO. 2

An Investigation of the Iron Ore Resources of the Northwest

BY
WILLIAM HARRISON WHITTIER
Research Fellow



SEATTLE
Published by the University
September, 1917

THE Bureau of Industrial Research of the University of Washington was established, January 21, 1916. Its functions are: (1) The co-ordination of the several departments within the University that possess expert knowledge of a given problem; (2) the study of industrial problems which have a general part in the upbuilding of the State; and (3) the undertaking of investigations of primary interest to the individual or corporation proposing them. The work of the Bureau is controlled by the President of the University and a faculty staff selected to take charge of the various problems under investigation. Communications to the Bureau should be addressed to the Director, H. K. Benson, University of Washington, Seattle, Wash.

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PREFACE

BY JOSEPH DANIELS

An iron and steel plant located in the Puget Sound area of the Pacific coast has long been the vision of many of the men who are building the greater Northwest. They see in such enterprise a great factor in the development of industry on the coast—one which will bring stability and prosperity to the community which is fortunate enough to initiate and successfully carry through the plans for this venture. But the establishment of an enterprise of this kind is one which cannot be lightly undertaken,—many factors involving raw materials, production, markets, finance, and related questions must be investigated and given careful consideration before the plan can be projected into the reality.

Part of the necessary investigation, that dealing with the supplies of iron ore, fuel, and fluxes; a discussion of the costs of production; markets, etc.; is here presented under the title of "An Investigation of the Iron Ore Resources of the Northwest." The work was done by William Harrison Whittier, research fellow, and presented as a thesis for the degree of Master of Science in the University of Washington. The financial problems involved in the promotion, construction, and operation of an iron and steel plant have not been considered here. It was thought best to limit the field of investigation to the discussion of the sources, amounts, and qualities of the raw materials, and to supplement this information with a brief survey of related economic questions. Necessarily, the question of financing and operating, while dependent on a survey and study such as is here presented, involves matters which are not in the province of this investigation.

The last word on the subject has not been said. Further work examining deposits, analyzing raw materials, working out methods of handling and treatment of ores must be done before our knowledge is complete. A more detailed study of the economic phases dealing with the costs of production, consumption of raw and manufactured iron and steel products, markets, and prices is necessary. Data gathered since this report was initiated is, in many instances, a record of the past rather than an index of the future, and proper allowance must be made for the fact that industrial and economic conditions today may be swept away tomorrow by the changing course of events. An earnest attempt has been made to present the results of an investigation and bring together a related mass of information which will serve as a starting point in any future consideration of the question of an iron and steel industry in the Pacific Northwest.

An Investigation of the Iron Ore Resources of the Northwest

INTRODUCTION

The great prosperity of the iron and steel industry in the United States during the last two years, due largely to an increased demand for iron and steel products in Europe and to a large increase in the consumption in this country, has resulted in numerous inquiries and speculations on the possibility of the establishment of an iron blast-furnace and steel industry on the Pacific coast.

It has long been contended by some individuals that the Pacific Northwest possessed the raw materials, with the possible exception of coke, necessary for the operation of an iron and steel industry, but that the small but growing market was too limited, the price of the product was too low, and the cost of production was too high to attract the necessary capital—in other words the time was not ripe.

But the last few years have witnessed a very marked change in the industrial conditions in this part of the country. The sharp advances in the prices commanded by all iron and steel products, the wonderful expansion of the local ship building and other industries using large quantities of these products, and the inability of the eastern steel mills to supply the heavy demands made upon them is unprecedented in the history of the nation. Under these conditions, an investigation of the subject seemed advisable. A group of Seattle and Tacoma business men, interested in the development of the cities' industrial activities, financed the plan for the investigation, and turned the matter over to the Bureau of Industrial Research of the University of Washington.

A plan of work was outlined and a fellowship established to carry on the work. A. S. R. Wilson, a graduate of the College of Mines of the University of Washington, was appointed geologist for the field season, and the writer was appointed fellowship holder to assist in the field examinations and to carry on the research work at the University.

The treatment of the question under consideration involved two lines of investigation: One, the field examination of iron deposits; the other, the necessary research work at the University, which included experimental work on the samples collected in the field, a study of

related resources other than those examined, and a consideration of the economic forces entering into the problem.

In accordance with the program for field investigation, A. S. R. Wilson and C. E. Weaver, of the geology department of the University, proceeded early in June, 1916, to Port Renfrew, British Columbia, and examined a deposit of black sand which was reported to exist in the vicinity of Lost river. Later, on June 28, Wilson and the author, as his assistant, were instructed to examine the magnetite deposits occurring on Texada island, British Columbia. The remainder of the summer was spent examining this deposit, and those occurring on Louise island, British Columbia; on Prince of Wales island, Alaska; and in collecting samples which were to be used later in the experimental work at the University of Washington. In September, 1916, the author undertook the research work of this investigation in the capacity of research fellow at the University and this report is an account of the results obtained.

The largest part of this report is necessarily taken up with a description of the iron ore deposits themselves. The other principal topics treated are the history of the iron and steel industry in the Northwest, the utilization of the iron ores, metallurgical experiments, coke, fluxes, costs of production, labor and markets.

The author wishes to express his appreciation to those who made possible the execution of this investigation and to those who assisted him in his work. He is especially indebted to the members of the Bureau of Industrial Research of the University of Washington and particularly to Professor Joseph Daniels, under whose direct supervision the work was carried on. He also wishes to thank Mr. William Fleet Robertson, Provincial Mineralogist of British Columbia; Mr. W. B. Henderson, of the United States Department of Commerce, Seattle; Mr. J. M. Mullin, Gold Commissioner, of Prince Rupert, British Columbia; Mr. A. M. Swartley, Engineer for the Oregon Bureau of Mines, who furnished valuable data and references; Mr. W. H. Lee, caretaker of the Texada island iron property; and Mr. W. J. Rogers and Mr. A. Carlson, manager and foreman respectively of the Mt. Andrew mine, for their courteous treatment during the field work.

Chapter I

HISTORY OF THE IRON AND STEEL INDUSTRY IN THE NORTHWEST

The first attempt at the establishment of an iron and steel industry on the Pacific coast dates back to 1865, when the Oregon Iron Company was organized and built a small furnace at Oswego, on the bank of the Willamette river, about seven miles south of Portland, Oregon. The first shipment of iron was made to San Francisco in 1867, and consisted of fifty tons. The only government records of the production of iron on the Pacific coast available to the writer date back to 1872 and so it is not known whether this furnace continued to produce during the four years following 1867. The annual reports of the Mineral Resources of the United States show that pig iron was produced in Oregon during the years 1874 to 1876, inclusive, 1878 to 1885, inclusive, and 1888 to 1894, inclusive. The industry was abandoned in 1894. During these years pig iron was produced only on a small scale. The largest year was 1890, when 12,305 tons were produced, and the smallest tonnage was 1,000 tons, which was produced in 1875. During the periods when the furnace was in operation the average annual production was about 5,000 tons. The property passed into the hands of the Oswego Iron Company in 1877.

Evidently the costs of production were too high to insure the permanency of this enterprise. That the costs were excessive is evidenced by the following extract from a description of Oregon iron which appeared in "Commerce and Industries of the Pacific Coast," in 1882:

The limestone, required for flux, is brought from the Tacoma quarries, in Washington, at a cost of \$5.50 a ton, and is used to the extent of 1,000 tons a year. About 140 bushels of charcoal and three tons of ore are required to produce a ton of iron. The cost of the charcoal would be \$9.10, and the ore is extracted and brought to the plant at a cost of \$2.10 a ton.

This would probably bring the total cost of producing a ton of iron to over \$20.00. In fact, the steel men of the Pacific coast stated in the publication quoted above that the cost of producing pig iron here in 1881 was \$24.00 per ton.

The Puget Sound Iron Company was organized in 1880. The principal shareholders were San Francisco and Oakland men, with Cyrus Walker as president. They erected a small plant at Irondale,

near Port Townsend, Washington, and began operating in February, 1881, and produced 1,200 tons of pig iron during that year. The company used Texada island ore, with charcoal for fuel, and made some pig iron which was reported to compare very favorably with eastern iron. But the venture was not a financial success, due largely, no doubt, to the limited market and the great slump in the price of the product during the years immediately following. In 1902 the property was taken over by the Pacific Steel Company, which was organized with Pittsburg and McKeesport capital. The plant was improved and included a 60-foot stack of 50 tons daily capacity, and a charcoal plant of 20 beehive kilns, each 30 feet high and 30 feet in diameter at the base and holding 75 cords of wood. Coke from Cokedale, Washington, was used until the charcoal kilns were in full operation. Numerous experiments were conducted on cokes produced in this section of the country with favorable results, disproving the popular opinion that no Washington coke is suitable for iron smelting.

According to "Mineral Resources of the United States," the years during which pig iron was produced in the state of Washington are 1881, and 1883 to 1889, inclusive. No pig iron was produced in this state from 1890 to 1897, inclusive, and the statistical reports for the years from 1898 to 1904 include pig iron of Washington with that of Colorado and Missouri. Evidently no pig iron has been produced at Irondale since 1904. Pig iron from China supplied this plant to the date of its shutdown in 1911. The Irondale venture failed for various reasons, chief of which were the high cost of charcoal, the limited market and poor management. Another attempt was made to revive the industry a few years later, but it also failed.

The Oswego and Irondale industries were, to the writer's knowledge, the only ones ever established in the Northwest for the manufacture of pig iron. A small amount of pig iron was produced in California, however, during the years 1881 to 1884, inclusive, and 1886 to 1887, the total amount manufactured in the state being 14,635 tons. The total amount of pig iron produced on the Pacific slope west of Colorado to date aggregates 128,839 tons. These figures exclude the production from 1898 to 1904, in which years the Washington production was grouped with other states. This is a remarkably small amount when it is recalled that one modern blast furnace of 500 tons per day capacity would produce the same amount in 258 days.

The only steel produced on the Pacific coast on a commercial scale has been manufactured principally from scrap in basic open-

hearth furnaces. In 1882 California produced 25,843 tons of rolled iron, including iron rails, and in 1886 her production was 30,967 tons. At the present time the plant of the Pacific Coast Steel Company at Youngstown, Seattle, includes two basic open-hearth furnaces of 50 tons per twenty-four hours capacity, both of which are now (May, 1917) being operated to their limit; one busheling furnace of 1,000 tons per month capacity; and one new basic open-hearth furnace of 50 tons per day capacity, which is just completed. An average of about fifty per cent pig iron and fifty per cent scrap is used in the open-hearth furnace. Some of this pig is imported from China and the rest comes from eastern United States furnaces. The same company controls a similar plant in San Francisco.

Summing up the history of the iron and steel industry on the Pacific coast, it is seen that very little progress has been made except in the manufacture of steel to a limited extent from scrap and imported pig iron.

Chapter II

UTILIZATION OF THE IRON ORES OF THE NORTHWEST

The possibilities of the utilization of the iron ores of the Northwest lie along four lines, namely, as fluxes in smelting other ores; in open-hearth steel furnaces as part of the charge; in the direct production of pig iron in the blast furnace; and in the production of iron and steel in the electric furnace.

USE OF IRON ORES AS FLUXES

Iron ores from various deposits in the Northwest have been employed as fluxes in different smelters, chiefly in the reduction of copper and lead ores, for many years and are still being used for that purpose. Their utilization along this line will always be, comparatively speaking, on a very small scale. This phase of the iron industry is relatively unimportant and requires no further comment.

USE OF IRON ORES IN OPEN-HEARTH FURNACES

Iron ores are utilized to a small extent in the manufacture of steel in open-hearth furnaces by two processes, known as the "pig and ore" process and the "pig, scrap and ore" process. The former is employed largely in Germany and scarcely at all in the United States, while the latter has met with increasing favor in this country. A small amount of ore is also used in the manufacture of wrought iron by the "puddling process."

The amount of ore consumed in all of these open-hearth processes, however, is small, seldom exceeding two per cent of the weight of the charge. The open-hearth furnace, except in a small way, is not to be considered as an important agency for the utilization of the iron ores of the Northwest.

USE OF IRON ORES IN BLAST FURNACES

The iron ore which is used in the manufacture of pig iron in the American blast-furnaces approaches very closely to 100 per cent of the total iron ore being consumed in this country today. It is to this field of use that we must look for the utilization of our iron ore resources.

In order that the ores of the Pacific Northwest may be utilized to the best advantage in the blast-furnace some of them will have to un-

dergo preliminary treatment. The pyritiferous magnetites will require concentration by magnetic separation, some may require roasting, and some of the other ores will have to be beneficiated in log washers. However, a large proportion of the ores can be used directly without any preliminary treatment and a great many more can be utilized by mixing them with higher grade ores.

It seems probable, therefore, that unless the direct production of pig iron in electric furnaces is found to be more feasible, the blast furnace will be the chief agency in the utilization of the iron ores of the Northwest, as it is in the big iron and steel producing states of the east.

USE OF IRON ORES IN ELECTRIC FURNACES

The only countries in which iron ores are smelted directly in electric furnaces on a commercial scale are Sweden and Norway. The electric furnaces in Sweden have displaced the charcoal furnaces, which were formerly used there in the production of the famous Swedish irons.

The furnaces employed are of two main types, the Elektrometall and the Heroult. Dr. Alfred Stansfield in his "Electrothermic Smelting of Iron Ores in Sweden" gives the essential features of these two main types as follows:

(1) The Elektrometall furnace, in which the ore is preheated and partially reduced in a shaft before it reaches the smelting chamber, the heating of the ore in the shaft and the chemical reduction of the iron in the ore being materially assisted by the circulation of the furnace gases, which is characteristic of this furnace.

(2) Furnaces of the Helfenstein, Californian and Tinfos type, in which there is no provision for preheating the ore. Any shafts employed are merely for the purpose of introducing the ore charge conveniently, and the main object of the design is to obtain a large and substantial furnace for smelting iron ores by electrical heat.

In drawing any conclusions as to the possibilities of the utilization of Northwestern iron ores in the manufacture of iron and steel in the electric furnace it is well to bear in mind the fact that this branch of iron and steel manufacture is still in the experimental stage everywhere except in Sweden and Norway. The cost of production of electric pig iron here would undoubtedly be considerably higher than it is in Sweden, where the industry is well established and the market assured. However, a considerable amount of magnetite in the Northwest is of a very fine quality and well suited to the electric furnace production of pig iron used in the manufacture of the finer grades of steel and ferro-alloys, and these ores could, therefore, be used in the electric furnace, particularly the higher grade magnetites and black

sands. The cost of production of pig iron in the electric furnace is somewhat higher than in the blast furnace and electrothermic smelting cannot compete with blast furnace smelting in cost. It is rather the higher quality of the product that enables the electrothermic smelting to exist. In other words, the two processes do not cover the same field. Electrothermic smelting is always necessarily carried out on a much smaller scale than blast furnace smelting and the control of the operation is much more delicate. Electric furnace plants might be profitably established in small units at various points along the Pacific coast for the manufacture of fine grades of iron and steel directly from iron ore. In view of the fact that the iron ore resources and markets of the Northwest are not at all to be compared with those of the east in magnitude, it is possible that the electric process may meet with better success in this part of the country. Considerable experimenting will have to be done, however, before this question is settled.

Chapter III

WASHINGTON IRON ORE DEPOSITS

IRON ORES IN GENERAL

Iron is the most widely distributed and also the most useful of all metals. It occurs in many different forms, but only four of these are important as iron ores. They are hematite, magnetite, limonite, or bog ore, and siderite, all of which contain more or less impurities. The principal impurities are phosphorous and sulfur. When an iron ore contains more iron than 1,000 times the phosphorous content it is classed as a bessemer ore—that is, an ore containing, say, fifty per cent iron and below five one-hundredths per cent phosphorous would be theoretically in this class; otherwise it would be called a non-bessemer ore, because it could not be successfully utilized in the bessemer process. In actual practice, however, about ten per cent of the iron is lost in the blast-furnace flue dust and so a fifty per cent iron must have less than four one-hundredths per cent phosphorous in order to fall within the bessemer limit. Sulfur is generally considered detrimental when the percentage present is greater than 0.20 to 0.30 per cent. In that case it is usually best to reduce the sulfur content by some treatment of the ore, usually magnetic separation or roasting, before smelting in the blast furnace. Silica, when running over ten to twelve per cent, is considered high and requires extra limestone to flux. Manganese, if present in quantities above two or three per cent, may be detrimental, but in the case of high sulfur ores, it may be beneficial. Titanium is difficult to fuse, causing sticky slags, and for this reason smelters are prejudiced against iron ores containing over one per cent of that element. Alumina, when higher in quantity than the silica, is also difficult to fuse. The content of iron in the ores mined today runs from thirty to seventy per cent. The average percentage of iron in the ores mined in the United States during recent years has been decreasing at the rate of about one-half of one per cent per year. At the present time the average is about fifty-three per cent. An iron ore running over fifty-eight to sixty per cent iron is considered high grade, while one running under fifty per cent is considered low grade.

Hematite is Fe_2O_3 and contains, when pure, 70.0 per cent iron. It is red to brown in color and may be hard and massive or soft and

porous. It is the best known and most important of all of the iron ores. Its most important occurrence is in the Mesabi range, Minnesota—by far the greatest iron producing district of the world. Large deposits of hematites occur in California.

Magnetite (Fe_3O_4) contains, when pure, 72.4 per cent iron. It is black in color, usually hard and massive, and is strongly magnetic. It usually contains a large amount of impurities. On the other hand, some of the magnetities of Sweden and Norway are the purest and highest grade iron ores mined. The principal occurrences are in Sweden, Norway, the Adirondack regions and the Pacific slope of North America, and Japan. Magnetite also occurs in the form of black sands in placer deposits along streams and beaches. When in this form more or less platinum and gold is often associated with it and the sands are sometimes mined for the precious metals, but they are seldom concentrated sufficiently to make them of value as an iron ore. These black sands occur over the entire length of the Pacific coast. The principal iron ores of the Pacific Northwest are magnetites, although hematites and bog ores also occur in some districts, notably in the Clealum, Hamilton and Valley districts.

Limonite or bog ore is $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ and contains when pure 59.8 per cent iron. It is brown and earthy in appearance, always contains a large amount of impurities, is invariably high in phosphorous, and seldom exceeds fifty per cent iron. It usually occurs in bogs or marshes. It is mined on a large scale in the southern states.

Siderite is iron carbonate, FeCO_3 , often called spathic iron ore. When pure it contains 48.2 per cent iron. It is not of much importance, except in England, where it has been mined for many years.

The total production of the various kinds of iron ores in the United States in 1880 was: hematite, 2,243,993 tons; brown ore, 1,918-622 tons; magnetite, 2,134,276 tons, and siderite 823,471 tons, making a total of 7,120,362 tons. The production of brown ore and magnetite has remained practically stationary up to the present time, while the production of hematite has increased enormously and that of siderite has dwindled to an insignificant amount. In 1914 the production was: hematite, 38,286,670 tons; brown ore, 1,537,750 tons; magnetite, 1,610,203 tons, and siderite 5,138 tons, making a total of 41,439,761 tons. The total production in the United States for 1916 was 81,095,000 tons.

The iron ore resources covered in this report include the principal known deposits of Washington, British Columbia, Alaska and Oregon.

PLATE I



MAP SHOWING DISTRIBUTION OF IRON, COAL AND LIMESTONE DEPOSITS IN THE NORTHWEST

It was thought advisable to include a short description of some of the more important deposits in California.

The principal iron ore deposits occurring in the state of Washington are included in four districts: the Clealum district in Kittitas county; the Snoqualmie Pass area in King county; the Hamilton district in Skagit county; and the Colville and Valley districts in Stevens county.

THE CLEALUM DISTRICT

The following description of the Clealum iron ore deposits is taken from three sources: (1) a paper presented at the Washington meeting of the American Institute of Mining Engineers, in February, 1900, by George Otis Smith and Bailey Willis; (2) a description of the iron ores of Washington by Professor S. Shedd of Washington State College, in Volume I of the Washington Geological Survey; and (3) the Snoqualmie folio (No. 139) of the United States Geological Survey; by George Otis Smith and Frank Cathcart Calkins.

These orebodies are located on the eastern slope of the Cascade mountains, along the Clealum river, about 23 or 24 miles above its junction with the Yakima river, near which point it is crossed by the Northern Pacific and the Chicago, Milwaukee & St. Paul railroads.

The ore outcrops along two distinct lines parallel to the river. One of these is in the valley near the river and can be traced from about one-fourth mile below Boulder creek up the valley to Camp creek, a distance of about one and one-half miles. The other line of outcrops extends along the ridge east of the river between Boulder and Camp creeks at elevations of 700 to 1,600 feet above the valley for a distance of about a mile. The outcrops are in the form of buttes and low ridges.

Character of the Ores

The iron ores are all presumably of sedimentary origin and are divided into three distinct classes by Shedd, as follows: massive, laminated, and oölitic.

The massive ore has a dull greenish-black color and when powdered being dark red in some cases and in others having a metallic appearance, but in each case giving a deep red powder or streak when pulverized. The oölitic ore has a greenish-black color and contains numerous oolites in an amorphous groundmass and when powdered gives a brownish-black streak. The laminated ore varies in appearance, or powder. All of these ores are quite strongly magnetic and are apparently mixtures of hematite and magnetite. In some of the ore bodies all three classes of the ore are found and in others only one class. The oölitic ore, so far as the writer could determine, is not found in the ore bodies farthest upon the hill, high above the river, but is quite common in those down near the river and especially those near Camp creek.

Geology

It is not the purpose of this report to enter into any extended discussion of the geology of the districts in which the ore deposits occur, except insofar as such geology has a direct bearing upon the probable continuity and nature of the orebodies beneath the surface. The geology of the Clealum iron district has been worked out very thoroughly by Messrs. Smith and Willis and a brief summary is here given.

The ores occur as a local basal conglomerate phase of the Swauk formation (Eocene), and lie unconformably upon Pre-Tertiary rocks. They are unquestionably of sedimentary origin. In addition to the mode of their occurrence and relation to the surrounding rocks, their chemical composition and physical structure strongly favor this view. Mr. Smith states that the ore stratum exposed in the valley, if followed by underground workings, would be found to dip northwest under Goat mountain at angles ranging from thirty to sixty degrees, but the nature and origin of the deposit indicate that this stratum could not be expected to be very thick or as continuous as a coal bed. The ridge ore deposits, it is said, would dip south at a higher angle.

Analyses

Smith states that analyses of ore from six different properties in this area indicate an iron content ranging from 48 to 56 per cent, but an average sample would doubtless run lower. A large sample taken by Willis for the purpose of collecting material as nearly representative of these iron ores as possible analyzed 42.5 per cent iron; 7.50 per cent SiO_2 ; 21.90 per cent Al_2O_3 ; 0.09 per cent P_2O_5 ; and 0.03 per cent sulfur. An average of five samples obtained by Dr. Edward Riley of London, England, gave the following results: 51.916 per cent iron; 0.04 per cent sulfur; 0.025 per cent phosphorus; 6.61 per cent SiO_2 ; and 7.684 per cent Al_2O_3 . An analysis of a sample of the best massive ore from the district by Shedd gave 57.12 per cent iron; no sulfur; no phosphorus; 5.68 per cent SiO_2 ; and 4.80 per cent Al_2O_3 and Cr_2O_3 . A sample of the poorest oolitic ore by Shedd yielded 46.24 per cent iron; trace of phosphorus; trace of sulfur; 7.50 per cent SiO_2 ; and 25.95 per cent Al_2O_3 . The ores appear to be low grade, with little or no phosphorus, sulfur, or manganese; low in silica, but high in alumina, which would make them refractory in smelting.

Genesis

Very strong evidence points to the underlying serpentine as the source of the iron which is here deposited. It is presumed that the

iron was concentrated into ore as the result of periodical weathering of the serpentine in certain patches or local basins, which were supposed for a time to be above the waters of the encroaching Eocene Swauk lake. It is pointed out that waters in such a drainage area would be heavily charged with iron and with organic material from decaying vegetation and that conditions were therefore favorable for precipitation of iron either as ferrous carbonate or as a hydrate of the sesquioxide in the shallow waters.

The writer quotes from the report of Willis and Smith as follows:

The conglomerates are exceedingly local in extent and when composed almost wholly of serpentine or granite are restricted to areas of those rocks underlying the conglomerate....The basal contact of the Swauk with the older formations is exceedingly uneven, and when traced out reveals the bold relief of the Eocene topographic surface, in which the soft shattered serpentine corresponded with lowlands. These depressions, which received little or no wash of other rocks than serpentine, may have been watersheds limited to areas of that rock. Here meteoric waters leached out soluble parts of the disintegrated rock, and the mantle of residual material was deep. The climate was sub-tropic and vegetation abundant.

If these interpretations are correct, it is evident that the iron ores are not widespread like the ores of the Lake Superior region. The conditions are favorable, however, for a considerably greater lateral extent beneath the surface than that of contact or replacement deposits with the same dimensions of surface exposure.

Other Iron Deposits in the Clealum District

According to F. C. Hunt, engineer for the Yakima Mines Exploration Company, iron ore occurs at the base of the Swauk formation in a series or chain of outcrops for several miles east of the Clealum deposits. The outcrops are said to consist of a series of bedded deposits whose surface extent ranges from 30 to 800 feet in length and from three or four feet to 300 feet in width. A hand specimen of the ore, which was said to represent a fair sample of a large deposit, is hematite of excellent quality and contains a very high percentage of iron, apparently entirely free from sulfides.

This ore is evidently of the same kind as the Clealum ore and is presumably of the same origin since it occurs at the same horizon in the same formation: namely, at the base of the Swauk, and in a general east line from the Clealum deposits. Mr. Hunt also states that there are other deposits at points about five and twelve miles southeast of Easton on Big creek and on the north fork of Taneum creek, respectively, and also at points near the headwaters of the south fork of Manastash creek. The deposit on Taneum creek is said to be ten feet

wide and to run 60 per cent iron. In any new survey of this district these prospects should be investigated.

Conclusions

It is impossible to state even approximately the quantity of ore available, as no estimates have been attempted by any of the men who have examined these deposits. It is evident, however, from the descriptions that the deposits are quite extensive in superficial area.

The ores are low grade and refractory, but it is possible that they could be mixed with some of the high grade magnetites of the Snoqualmie Pass district or of British Columbia, which are in themselves quite high in silica and sulfur, and obtain a suitable mixture for the blast furnace. A blast furnace plant, if located on Puget Sound, would necessitate the transportation of the Clealum ores over the mountains to tidewater, a distance of eighty miles, about thirty miles of which would be up-grade. It would also necessitate the building of 23 or 24 miles of tram road from the deposits to the railway.

These ore deposits would warrant further consideration in the event of the establishment of an iron and steel industry on Puget Sound, but are not now of immediate influence in the discussion of the establishment of a blast furnace.

THE SNOQUALMIE PASS AREA

The only known deposits of magnetite of economic importance occurring within the state of Washington are two bodies outcropping near the summit of Snoqualmie pass, in King county. They are known as the Denny and Guye prospects and both are near contacts of the Snoqualmie granodiorite with the Guye formation, which is composed of interbedded grit, slate, chert, limestone and basalt of early Miocene age. Both deposits are considered as contact replacements, both because of the fact that they are located near contacts and because the typical contact minerals, garnet, quartz, green hornblende and calcite are present in abundance and are well crystallized.*

Denny Prospect

The Denny prospect is located on the west slope of Denny mountain, about two miles west of Snoqualmie pass at an elevation of 3,400 feet. The deposit here constitutes a mineralized band which is bounded on the west side by a bed of massive garnet, in places ten feet wide. The band is parallel to one of the joint planes in the granodiorite.

*Snoqualmie Folio, No. 139, U. S. G. S.

which is much fractured and jointed and which strikes nearly north and south. Next to the massive garnet bed are quartz, green hornblende, calcite, and garnet—all well crystallized. The ore is said to occur as a brecciated material, the nodules of magnetite being up to one foot in diameter. Masses of pyrite crystals are associated with the nodules of ore. At other openings on the property pure solid magnetite is exposed as outcrops in veinlike lenses up to twenty feet or more across, but the showings are rather deceptive of the extent of the ore bodies because the lenses lie approximately parallel to the surface, thus exposing their maximum dimensions. At one point a vein of magnetite outcrops and is bordered by parallel bands of massive garnet and calcite. It is supposed that the magnetite is the oldest and the calcite the youngest. Two analyses of ore from the Denny prospect are reported by Fulmer and Shedd as follows:

	(1)	(2)
Iron	62.45	68.54
Sulfur	0.21	0.25
SiO ₂	5.78	1.89

The deposits of this prospect are well situated for cheap mining and transportation. Fulmer and Shedd state that the surface showings are not such as are indicative of the existence of ore bodies of any greater size than those outcropping on the surface. Considerable pyrite occurs with the magnetite, which would make the sulfur content high. A large part of the ore, however, could probably be segregated by hand picking so as to have it comparatively free from sulfur. In the light of these facts it is evident that a considerable amount of development work will be necessary to prove the importance of the prospect.

The Guye Prospect

The Guye prospect is situated about $1\frac{1}{2}$ miles due north from the summit of Snoqualmie pass, on the south side of Snoqualmie mountain, at an elevation of about 4,500 feet. The magnetite deposit here is also near the contact between the granodiorite and the Guye formation. Characteristic contact minerals are also present. Conditions in general, therefore, are the same as at the Denny prospect, except that the limestone phase of the Guye formation is here in actual contact with, and has been replaced by ore. The magnetite also occurs in considerably larger quantities than at the Denny prospect and the surface indications are said by Shedd and Fulmer to be much more favorable for continuity of ore at depth than at the Denny prospect.

George Otis Smith states that large blocks of fairly pure ore can be taken out here. Two analyses of the ore by Shedd and Fulmer gave the following results:

	(1)	(2)
Iron	66.81	66.82
Sulfur	.....	.....
Phosphorus	Tr.	.....
SiO ₂	3.60	4.20

Some of the ore is said to be associated with pyrite and would carry considerably sulfur, but on the whole it is of excellent quality.

Smith and Calkins consider that these magnetites are probably derived from the granodiorite as replacements of the intruded rocks during the latter stages of the intrusion. The evidence seems to point toward simultaneous deposition of magnetite and pyrite with slight subsequent concentration of the former by the oxidation and decomposition of the pyrite and of garnet. The magnetite is therefore considered as derived principally from the original solutions which also deposited the other contact minerals. If this assumption is correct and because the magnetite replaces limestone at its contact with the granodiorite the indications are favorable for the uncovering of larger ore bodies by systematic development work.

The Guye prospect is more favorably situated for cheap transportation than is the Denny. Plenty of water and timber are also present which would facilitate cheap mining. The ore is of excellent quality. The quantity present, however, is entirely unknown owing to lack of development work. In the event of the establishment of an iron blast furnace on Puget Sound this prospect would justify a thorough investigation. If any considerable quantity of ore is proved here and at the Denny prospect it could very probably be mixed with some of the lower grade Clealum or Hamilton ores to form an excellent charge for the iron blast furnace.

THE HAMILTON DISTRICT

The iron ores of the Hamilton district are the only ones in the state of Washington, outside of limonite, which occurs in the Chimacum valley, which have ever been utilized in the manufacture of iron. In 1902 and 1903 the Pacific Steel Company used a small proportion of Hamilton ore as a "mix" with Texada ore in their blast furnace at Irondale. The quantity used was insignificant in magnitude, but demonstrated clearly that an excellent pig iron of bessemer grade could be manufactured from a mixture of these two ores.

Conditions in Skagit County

The iron ores under consideration occur in several long lines of outcrops above the town of Hamilton, Skagit county. These deposits were not examined by the writer and the only available report on them is the one by Solon Shedd, which appears in Volume I. of the Washington Geological Survey Annual Report. Most of his description is reprinted here as follows:

In Skagit county along the south bank of the Skagit river from Hamilton to Marblemount occur deposits of iron ore which are very favorably situated as far as fuel, fluxes and transportation are concerned. There are five different veins or ore bodies in this district, ranging in thickness from 6 to 50 feet, and dipping to the south and a little to the west at an angle of 55 degrees.

Just above the iron ore occurs coal which is said to be of coking quality and in large quantities, but at present (1901) nothing is being done to develop these deposits. About 12 miles west of Hamilton, at Cokedale, deposits of good coking coal occur and the coke from here could be used in connection with the Hamilton ores should it be found on further investigation that the Hamilton coals are not coking coals. Limestone suitable for flux is found in close proximity to the iron ores of this locality, and a few miles east of Hamilton large quantities occur.

The Location and Mode of Occurrence of the Ore

The iron ore deposits in the Hamilton district occur on the south side of the Skagit river at Hamilton, in the western spurs of the Cascade range, about twenty-five miles above the mouth of the river. Deposits have been found as far up the river as Marblemount, which is about twenty-five miles above Hamilton. The country rock through this locality is sandstone, limestone, shales and slates. The iron ore occurs in the slates and lies parallel with the bedding. Occurring in connection with the iron in this district, especially across the river from Hamilton, and lying above it are at least four seams of what is said to be a good grade of coal.

Extent of Iron Deposits

Outcrops of iron ore appear at intervals along the valley from Hamilton to Marblemount, a distance of twenty-five miles. While the deposits have been found in a number of places along the trend there has not been work enough done to tell definitely just what the relations of the different outcrops are to each other, but I am inclined to think they are lenses rather than veins and probably not continuous between the outcrops. The ore bodies vary in thickness from a few feet to 30 feet. From Hamilton to Birdview, a distance of six miles, the iron ores appear at intervals on the south side of the Skagit river in five lines, one above the other, while at Marblemount only two lines of outcrops have been found so far. These outcrops trend approximately east and west and have a dip to the southwest of about 55 degrees.

Character and Composition of the Hamilton Ores

The Hamilton ores are dark colored, massive appearing ores, having a medium specific gravity, for an iron ore, and when powdered some of them have somewhat of a reddish appearance, while others have a very dark, almost black appearance. The ores are all more or less magnetic. The reddish cast to the powder, however, shows that they contain some hematite in places, as, for instance, in the tunnel on the Inaugural claim, the iron is found to be intimately mixed with a very white granular quartz, but most of the district seems to be free from this.

Following is the table of analyses of the Hamilton ores, as reported by Shedd:

Mine—	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	P ₂ O ₅	S	Fe	Mn ₃ O ₄	CaCO ₃
Inaugural	19.98	62.70	3.30	0.25	.....	43.89	12.30	3.98
Hamilton	30.53	45.92	7.25	0.72	0.06	32.14	11.74	5.82
Hamilton	20.24	52.46	7.40	Tr.	.....	36.72	13.04	9.77
Inaugural	31.82	44.40	6.79	0.41	Tr.	31.08	14.28	5.83
Hamilton	32.94	48.40	2.57	2.43	0.16	33.88	7.31	8.81
Inaugural	18.36	62.73	3.09	1.58	.....	43.91	12.00	8.92
Tréadwell	22.85	62.46	3.17	1.00	.....	43.72	8.08	3.78
Pittsburg	28.05	47.03	8.43	0.70	.....	32.92	8.11	8.06
Pittsburg	32.46	41.59	8.56	0.45	.....	29.11	13.11	6.71

(All analyses by Thatcher)

The samples from the Inaugural mine are sufficiently high in manganese and silica to make a fairly good grade of silico-spiegel. These samples, according to Shedd, were taken from the surface from a tunnel 50 feet in length and from a shaft 85 feet in depth at this mine.

All of the samples are quite low in iron and high in silica and phosphorus, and rather high in manganese for good iron ores.

Conclusions

All of the analyses show these ores to be of very poor quality. It is possible, however, that they might be washed in log washers at a very low cost, improving their quality by reducing their phosphorus content and at the same time increasing their iron content. It is also possible that these ores might be mixed in small proportions with the high grade low phosphorus magnetites of the Northwest in order to produce a desirable mixture for the blast furnace. As a matter of fact, this has already been done. Their physical characters would make them desirable for this purpose.

It appears from Shedd's report that the conditions surrounding the deposits are quite favorable for cheap mining and transportation. As far as known, no tonnage estimates of the Hamilton deposits have been made. The description by Fulmer and Shedd indicates that the deposits are quite extensive.

THE COLVILLE AND VALLEY DISTRICTS

Iron ores consisting of limonite, hematite and magnetite of considerable extent occur in the Valley district, Stevens county, Washington. Only two reports on these deposits are known to the writer. One of these reports is by Solon Shedd and appears in Volume I. of

the Washington State Geological Survey Annual Reports, 1901, and the other is by C. K. Leith, of the United States Geological Survey, who visited the district in 1904, and is found in Bulletin No. 285, pages 194 to 200, of the United States Geological Survey.

The principal part of Shedd's report is quoted as follows:

The Mode of Occurrence of the Ores

The general character of the region in which the iron ores of Stevens county occur is that of a mountainous country with comparatively level valleys of considerable extent along the larger streams. The mountains rise gradually until an altitude of from 2,000 to 3,000 feet above the valleys is reached. The rocks of this region are limestones, shales, slates, serpentines, porphyries, and marbles. The ores occur both in veins and in bedded deposits, principally in the limestone and porphyry.

Character and Composition of the Stevens County Ores

The ores of Stevens county are principally hematites and limonites, and vary in appearance and texture from a very compact metallic-appearing mass to a finely divided loose red powder which has been used very successfully as a paint. Some of these ores scattered profusely through the mass have small octahedral crystals of magnetite.

The ore from the Clugston Creek district is a limonite or bog ore of a porous nature and ranges in hardness from a soft, decomposed ore to a hard, flinty ore. When pulverized it gives a brown streak and powder. The ores east of Valley are limonites, having a deep red to almost black color, and when pulverized vary in color from a brown to dark red, indicating that in some cases, at least, there is hematite present. The ores from west of Valley are hematites with some magnetite and vary in appearance from deep red to metallic. These ores when pulverized give a deep red streak and powder. The ores of Stevens county carry a high per cent of iron, running from 50 per cent to as high as 68 per cent metallic iron.

The Clugston Creek District

This district is about twenty miles north and a little west of Colville in Sec. 11, T. 39 N., R. 37 E. The country rock in this district is a limestone and the iron ore seems to occur in masses, and not in a continuous vein, in the limestones and varies from well concentrated iron to limestone with very little iron ore in it. Two tunnels have been run on one of these properties, and at the end of the lower tunnel a shaft sixty feet deep has been sunk so that a depth of 100 to 120 feet has been reached on this property. In the upper tunnel considerable ore was found, but in the lower one and in the shaft no ore was found. The ore in this district from present indications, so far as I was able to judge, is of very limited extent.

Analyses of Iron Ores from Stevens County

Mine—	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃ and		P ₂ O ₅	S	Fe	P
			Cr ₂ O ₃					
Silver King, Valley	1.66	96.51	.....	.....		0.38	67.56	.....
Silver King, Valley	1.12	97.28	.....	.....		0.25	68.10	.....
IXL, Colville....	4.49	80.08	2.00	0.72		0.32	56.58	0.31
IXL, Colville....	14.90	72.12	2.48	0.68		0.32	50.48	0.30
Capital, Valley...	5.80	84.55	1.85	0.36		0.33	59.19	0.16
Vigilant, Valley..	3.54	83.62	3.18	0.51		0.21	58.53	0.22

(All analyses by Shedd)

These results all show very good grade iron ores, though too high in phosphorus and sulfur for bessemer ores. Most of these ores are of a porous nature, and, being low in silica, would make an ideal mixture with the high grade, massive magnetites of British Columbia and Washington.

Mr. C. K. Leith's report on this district, which appears in Bulletin No. 285 of the United States Geological Survey, is substantially as follows:

Visits were made in 1904 to ore deposits in Stevens county, northeastern Washington. Southeast of Northport, near Deep Creek lake, both northeast and southwest of the lake, yellow porous limonite occurs associated with limestone, resting on the flank of the mountains. The ore is exposed in a considerable number of pits and drifts. On the way to the area the cores of the mountains were observed to be granite flanked by limestone. No igneous rock was observed near the ore, but presumably, from the general structure of the region and analogy with other districts, it occurs not far away.

About 14 miles west of Valley is a shaft 75 feet deep, from which have been thrown out fine dense hematite, coarse amphibolitic martite ore and gradations between the two; also green schistose rocks whose relations to the ore were not determined. To the east sericitic slates may be seen dipping under the shaft and to the west of these are limestones, presumably forming the hanging wall.

To the southwest, on the Roger's claim, several drifts were observed penetrating limestone with a small amount of hematite near the surface, suggesting a surface replacement of the limestone. Higher up the hill ferruginous slate and magnetitic slate locally called jasper and indeed somewhat resembling jasper, are exposed. The relations to the limestone are unknown. Diorite was observed along the road in such relations as to indicate its lower stratigraphic position. From what the writer observed and from the discussion with local prospectors, there is apparently in this region more or less ferruginous alternation of the limestone near its base, where it rests on slate. The occurrence of diorite intrusives in the vicinity suggests a possible genetic relation.

About six miles east of Valley limonite occurs between andesite, forming the core of the large hill and limestone resting upon its flank. The ore is in general soft, hydrated hematite and limonite of red and brown colors, and very porous. Locally the ore seems to dip toward and under the andesite, which is spoken of as the hanging wall. There is evidence here also of some brecciation, faulting and folding, some of it later than the formation of the ore. Near the contact with the ore both the andesite and the limestone are much altered and are represented by clay showing the texture and structure of the original rock. Stringers of the ore run both into the limestone and into the andesite. For the most part the contacts are very sharp. The extent and shape of the deposit has not been determined. A thickness of 20 feet was observed in one place and less in others.

Two samples of the iron ore from the Capital mines, near Valley, were received by the writer from Mr. S. B. Coon of the Spokane Chamber of Commerce. These samples were assayed and the following results obtained:

	(1)	(2)
Iron	41.70	51.50
SiO ₂	10.30	10.80

Phosphorus	0.117	0.116
Sulfur	Tr.	Tr.
Manganese	0.37	0.19
TiO ₂	0.25	0.30

Sample No. 1 is a brown bog ore or limonite and very porous. Sample No. 2 is a dark red, rather massive ore which gave a very deep red powder when pulverized. This is apparently hematite. These samples, although rather low in iron, have excellent physical qualities for blast furnace ores.

Conclusions

It is impossible from Shedd's and Leith's reports to form any conclusion as to the probable extent of the areas of the Colville and Valley district, except that it is considerable.

No theory of the genesis of the ores is advanced by either of the examiners, though it is stated that certain field relations suggest concentration under the influence of igneous intrusions.

The ores are apparently of very good quality, both chemically and physically, although too high in phosphorus and sulfur to be classed as bessemer grade. They would, however, make an ideal product by mixing with magnetites.

Transportation is an important factor in arriving at any conclusion as to the commercial importance of any iron deposit. In this case it is the writer's belief that the obstacles to be overcome in transporting the ores to tidewater—namely, 400 or 500 miles of rail transportation and the crossing of the Cascade mountains, are too great to make the deposits of much commercial importance at the present time unless a blast furnace plant were established in eastern Washington.

BELCHER DIVISION OF THE REPUBLIC DISTRICT

Bulletin 550 of the United States Geological Survey, 1914, by Howland Bancroft, on pages 173 and 174, gives a description of a deposit of magnetite of some extent which occurs on what is known as the Copper Key claim at an elevation of 4,650 feet, on the west side and near the top of Belcher mountain. This mine, it appears, has been worked for gold and silver.

A part of Bancroft's description is as follows:

The rocks in the vicinity are limestone, dolomite, lime shales, and argillite, very similar to those found in other parts of the Belcher mining district. These rocks strike northwest and dip 15 to 30 degrees southwest. They are intruded in several places by monzonite porphyry, which has caused some contact metamorphism in the contiguous strata.

As exposed by the workings in the Copper Key, the ore bodies represent an irregular replacement of limestone or dolomite by pyrite, pyrrho-

tite, and magnetite, with some chalcopyrite. They follow the general trend of the strata, which they replace, and locally they lie directly above or beneath the intrusive porphyry. One ore body exposed by the upper workings has been developed for 100 feet or more along its strike and for over 100 feet along the plane of the dip. Its width is approximately 25 feet. It is possible, or even probable that this ore body is a continuation of the one exposed on No. 2 level, where an ore body has been shown to continue at least 90 feet along its strike and to be 25 feet thick, but no work has been done to show its extent along the dip plane.

No. 3 level cuts the ore body which extends as a more or less complete replacement for 30 feet along the strike, the mineralization beyond being scattered and less prominent until it almost entirely disappears. This ore body, as developed, seems to be only 4 to 6 feet thick. Its extent along the dip has not been determined. Probably it represents a distinct ore body, having no immediate connection with the ore exposed in the level above. It is possible, though improbable, that the orebody exposed above has been faulted down. At the time of visit not enough work had been done to show the containing walls of this lower ore body.

The unoxidized ores carry from 0.08 to 0.25 ounces of gold and 0.14 to 0.46 ounces of silver to the ton and less than 1 per cent of copper. In the upper parts of the deposit, where there is a heavy gossan of limonite about 20 feet thick, the gold content is about the same, but the copper content is lower. An analysis of a specimen of magnetite ore by J. G. Fairchild, of the United States Geological Survey, is given below:

Analysis of Magnetite Ore from Copper King Mine

Iron (Fe_3O_4 87.28)	63.210
SiO_2	0.640
CaO	8.780
MgO	1.100
Sulfur	0.080
P_2O_5	0.164
As	None

As a large quantity of this magnetite is present in the ore body and as in places it is remarkably free from pyrite and pyrrhotite, it may possibly be of economic importance.

The geological relations existing at the mine are apparently favorable for the probable existence of deposits of magnetite of considerable extent, although no very large deposits are exposed. In conclusion it might be stated that not a great deal has been proved for or against this mine as a source of iron ore. It is well to recognize, however, that this deposit is located so far away from tidewater that it is not likely to become of any commercial importance as an iron producer for some time, especially in the light of the fact that large deposits of high grade magnetite exist in close proximity to water transportation.

MISCELLANEOUS DEPOSITS OF WASHINGTON

Besides the deposits already cited, certain so-called iron ores are reported to occur in the Lake Cushman district, Mason county; in the Black hills of Chehalis county; and near Chimacum, Jefferson county. None of these, however, is of any commercial value as iron ores. Some

of the Lake Cushman ore, however, might be of value as a source of manganese. In fact, some of this ore has been mined by a Tacoma company and used in the manufacture of ferro-alloys by electro-thermic smelting. One sample of this ore is reported by Shedd to have been assayed by Fulmer and to have yielded 45.58 per cent Mn_3O_4 .

TONNAGE ESTIMATES OF IRON ORES OF THE STATE OF WASHINGTON

None of the iron ore deposits within the state of Washington was visited by the writer and none of the reports available gives any estimates of tonnage. It is impossible therefore to give any tonnage estimates with any degree of accuracy. After studying the various descriptions of the deposits it is only possible to state certain limits within which the "possible tonnage" of ore would probably fall. According to the writer's estimate, the range of tonnage varies between 10,000,000 and 50,000,000 tons.

Chapter IV

BRITISH COLUMBIA IRON ORE DEPOSITS

The principal iron ore deposits in British Columbia, which are of commercial importance, are located along the coast in close proximity to tidewater. There are some deposits also in the interior which may become important at some future time. The deposits described in this report are those which are located along the coast on Texada, Vancouver, and Louise islands, and on a tributary of the Zymoetz river in the Omineca mining division of the Prince Rupert district. The deposits in the latter district are of limonite or bog ore, as are also certain deposits on Quatsino sound, Vancouver island. All of the other coast deposits are of magnetite.

TEXADA IRON ORE DEPOSITS

Location and Ownership

Texada island is the largest island in the strait of Georgia, being about 30 miles long and 6 miles in width, at its widest part. The principal port of call of steamers is Vananda, which is located on Vananda bay, on the northeast coast of the island, about 5 miles from its northwest end and about 70 or 80 miles from Vancouver. The Texada iron ore deposits occur on the northwest coast of the island about 6 miles from Vananda, along a ridge which parallels the coast, and is known locally as the iron range. The principal occurrences are at elevations of 400 to 800 feet and at distances of $\frac{1}{4}$ to $1\frac{1}{2}$ mile back from the seashore. The iron deposits are included within an area which measures $\frac{1}{2}$ mile in width by $1\frac{1}{2}$ miles in length and are owned by the Puget Sound Iron Company of San Francisco.

General Statement

The geology of Texada island was worked out by R. G. McConnell of the Canadian department of mines and his assistants and was published as Memoir 58 of that department in 1914. The writer, in company with A. S. R. Wilson, spent above five weeks examining the iron ore deposits under consideration, but in view of the limited time available for complete study the following report and particularly that part dealing with the geological features is taken largely from the publication mentioned above, and is supplemented to some extent by observations of the writer and Wilson dealing with the ore deposits.

General Topographic Features

In describing the relief of Texada island, Mr. McConnell says:

Except for limited movements of elevation and depression, Texada island has not been noticeably disturbed since Cretaceous time, at least, and the present topographic forms are the results of long continued erosion. The softer rocks represented by the Cretaceous sandstones and shales, and limestones, probably of lower Mesozoic age, have been worn down into basins and rough seaward sloping plains, while the more resistant rocks such as the porphyrites, project as hills and ridges.

Erosion has apparently reached a much later stage than on the mainland as the hills are much more rounded and worn than the jagged and precipitous mountains to the east. The highest peak on the island is Mt. Sheppard, which is about five miles from the southernmost extremity and reaches an elevation of 2,892 feet. The southern end of the island possesses a much sharper relief than the northern portion, which is, generally speaking, considerably lower in elevation.

General Geology

That portion of the island known as the iron range is comparatively free from underbrush and superficial deposits and the rocks are therefore well exposed and easily studied.

The respective ages of the formations outcropping on Texada island are not well established owing to lack of fossil evidence. However, marine fossils have been found in one formation which is thereby correlated with the coal bearing series on Vancouver island and definitely identified as of Cretaceous age. Through the field relations and lithology of the other formations, McConnell has assigned each one a tentative place in the geologic time scale, placing them all in the Mesozoic era, with the exception of three small areas of superficial deposits, which are of Quaternary age. His classification is as follows:

QUATERNARY	{	Holocene or Recent=creek gravels, peat, etc.
		Pleistocene or Glacial=boulder clays, sands, silts, etc.
		Cretaceous=soft sandstones, sands, clays and shales.
MESOZOIC	{	diorites and diorite porphyrites
		in small stocks and dykes.
		Jura-Cretaceous=
		quartz diorites referred to the
		period of Coast range batholith.
	{	Lower Jurassic=Texada group; porphyrites. Texada group of Leroy (in part).
		Lower Jurassic or Triassic=Marble bay formation; limestone.
		Triassic (?)=Anderson bay formation; schists, tuffs, agglomerates, amygdaloids, and marbles. Texada group of Leroy (in part).

Anderson Bay Formation—The Anderson Bay formation, which is the oldest in the district, has been found to outcrop only at the southern end of the island, where it occupies an area extending up the east coast for about 7 miles and having an average width of about $\frac{3}{4}$ mile. It is described by McConnell as follows:

The Anderson bay formation is the only distinctly bedded and banded formation on the island. It is made up of an alternating series of slates, quartzites, conglomerates, marbles, tuffs, agglomerates, amygdaloids, and reddish lead-colored and green schists. The beds and bands are highly tilted as a rule, dip to the west and strike in a northerly direction. The different varieties have all been subjected to intense dynamic metamorphism, and nowhere occur in their original condition. Limestones have been altered to marbles, argillites, and fine-grained tuffs into schists or quartzites, and even the massive flow rocks have been crushed in places into coarse schists.

Marble Bay Formation—The Marble Bay formation consists entirely of limestone, which occupies two large areas, one at the north end of the island and the other in the central portion of the island on the west coast, together with many smaller outcrops north of the latter. The limestone, generally speaking, is remarkably free from impurities, and in the vicinity of the iron range and near its contacts with intrusive rocks is found to be white and coarsely crystalline when freshly broken, although weathered surfaces are bluish black. Bedding planes are nearly always entirely obliterated, but where they have been tilted at high angles weathering and erosion have produced small parallel ridges from an inch to several feet across with sharp depressions or crevices intervening. A few fossils, very imperfectly preserved, were found in this formation by Walter Harvey of Victoria and were identified to be either of Jurassic or Triassic age.

Texada Formation—By far the largest part of the island, perhaps four-fifths, consists of basic intrusive rocks, probably of Lower Jurassic age, which vary greatly in mineral composition from that of a basalt to that of a dolerite or diorite porphyry and which have been collectively termed porphyrite by McConnell because of their porphyritic structure. The area occupied by this formation extends from near the north end of the island to within a mile of the south end and is completely broken only south of Vananda, where the Marble bay limestone extends almost across the island to the iron range. Typical specimens of this porphyrite are found to consist principally of phenocrysts of plagioclase feldspars and augite in a finer-grained groundmass of the same minerals. Accessory minerals are magnetite, which is quite common, zoisite, epidote, actinolite and chlorite, most of which are alteration products. Hornblende is often present and is sometimes seen

under the microscope to be secondary after augite. These rocks are nearly always massive in occurrence, but sometimes possess a peculiar structure designated by McConnell as "ropy" and sometimes more or less botryoidal structure, resembling boulders of exfoliation common in weathered basalt. Regarding their origin, McConnell says:

The porphyrites, while varying widely in texture, and appearance, are considered to form, viewed broadly, a single igneous body. Later dykes and small stocks intruding the main mass occur in places, but owing to their lithological similarity to the older rocks and the obscuring of the boundaries by alteration, can seldom be satisfactorily differentiated.

Batholithic and Dyke Rocks—Intrusive rocks which are later than the porphyrites and more acid in composition occupy three areas, two on the east coast and one on the west coast in the vicinity of the iron range, together with numerous small areas in the northern part of the island. The three localities referred to are nearly equal in size and comprise a total area of perhaps three square miles.

These rocks, because of their lithological relationship to those comprising the great coast range batholith, are considered as a part of that body. They contain many varieties of acid intrusives, which are considered as differentiated phases of the same magma. The principal rocks of this formation are classified by McConnell as quartz diorites, which are by far the most extensive; syenite porphyrite, which is found in two dykes; augite syenite, which occupies a small area near the Prescott iron mine; diorites, which are confined to small areas in the vicinity of Vananda and Blubber bay; diorite porphyrite dykes, which are distributed over nearly the entire island; and one quartz porphyry dyke, which outcrops at Blubber bay.

These batholithic and dyke rocks are considered to be important because the iron ores were presumably derived from the same magma and deposited during the later stages of the intrusion. Their mineral composition, generally speaking, consists of plagioclase and subordinate orthoclase feldspars, hornblende, augite, biotite and quartz. The principal accessory minerals are apatite, ilmenite, marcasite, pyrite and magnetite, which is always present and usually abundant. The structure of these rocks is invariably massive.

Cretaceous Rocks—The Cretaceous rocks, since they have no direct connection with the iron ore deposits, are not considered important, except as they furnish the principal basis of determining the relative ages of the different formations of the island. They are of sedimentary origin, being composed of bedded clays, sandstone, conglomerate and coarse shales, and contain fossils which have definitely established them as of Cretaceous age.

Superficial Deposits—Glacial drift covers small areas and erratic boulders of glacial origin are scattered over the island to the highest elevations, but generally speaking, the superficial deposits cover insignificant areas and are unimportant.

Distribution of the Deposits

The deposits consist of a large number of irregular, roughly lenticular-shaped bodies which, being harder than the surrounding rocks, usually project above them, often forming the point of a ridge or brow of a hill. They are included within an area which has been mapped by McConnell and measures about $1\frac{1}{2}$ miles in length by $\frac{1}{2}$ mile in width.

Classification and Field Relations of the Iron Deposits

The deposits are typically metasomatic, that is, they were formed contemporaneously with or immediately following an eruption of igneous rocks and replace the intruded rock, and to a lesser extent the intrusive rocks. They are presumed to have formed at considerable depth and under high temperature conditions, as is indicated by the coarsely crystalline character of the limestone and epidote garnet rock near the contact, by the magnetite itself, and by the mineral composition of the deposits.

The ore occurs in very irregular-shaped bodies of all sizes up to that of the Prescott ore body, which is some 300 feet in length by nearly 100 feet in width and which has been proved to a depth of 430 feet below the highest outcrop. The ore is found at or near the vicinity of the contacts of the quartz diorite or of the porphyrite with limestone and also along porphyrite-diorite contacts. Some lenses are also found entirely surrounded by porphyrite, some by limestone and some by diorite. Regarding those deposits surrounded entirely by igneous rock it seems to be the opinion of C. K. Leith that they have entirely replaced lenses or fragments of limestone, which have been caught up in the intruding rock. In Bulletin 285 of the United States Geological Survey, on page 199, in speaking of the Vancouver and Texada island deposits in general, Mr. Leith says:

The ores occur at or near the contact of acid igneous rocks with limestone and are obviously replacements of limestone. In some instances the ore may be seen entirely surrounded by igneous rock, evidently a replacement of limestone intruded by and caught up in igneous rock near the contact. The contacts of the igneous rock with the ore are characteristically sharp and present no gradation features that would accord with the view that the ore represents segregations from igneous rocks. The abundant occurrence of lime garnet, however, both in the ore and in the crystal, suggests the concentration of the deposit under the influence of igneous intrusions.

Age of the Deposits

McConnell considers the ores to have been deposited toward the latter part of the last period of igneous activity on the island. He says:

The age of the magnetite deposits is considered to be Lower Cretaceous. They originated during the closing stages of the coast range batholithic invasion, an invasion which commenced in the Jurassic and continued into early Cretaceous times.

Mineralogy of the Ore Deposits

The principal metallic minerals are magnetite, pyrite, pyrrhotite, chalcopyrite, and marcasite. A little specular hematite and siderite were also observed. Non-metallic gangue minerals are garnet, epidote, calcite, quartz, actinolite, tremolite and diopside.

Description of Occurrences

Prescott Mine—The Prescott mine shows the greatest amount of development work of any of the mines or prospects on the iron range and therefore has the greatest amount of proved ore. The outcrop constitutes the end of a ridge which stands out prominently as a black hill above the surrounding less-resistant rocks and may be plainly seen from passing steamers. The ore bodies at this mine are surrounded by contact rock which occurs as a replacement of both limestone and diorite at their contact in one of the numerous so-called "limestone bays." This contact rock is composed principally of garnet, epidote, magnetite, actinolite, calcite and quartz, with considerable pyrite and marcasite in places.

Development work at the Prescott mine comprises three large open-cuts; one short tunnel about 20 feet long, driven in solid magnetite at the base of the largest open-cut; one shaft, 150 feet deep; a tunnel, 755 feet long; and an old surface tram road about 1,000 feet in length, which connects the largest open-cut with the beach. This surface tram and the old bunkers have been destroyed by fire. A new wharf was built at a point immediately below the entrance to the lower tunnel during the summer of 1916 and bunkers and surface tram were in the process of construction by a leasing company with the intention of working the copper deposits which border the magnetite on the seaward side.

A large open-cut has been made on the east side of the ore body, at an elevation of 520 feet, which has an average width of about 50 feet, a length of about 100 feet and is 35 feet wide by 50 feet high at the face. The ore body on this level is about 300 feet long. A

sample taken across the 35-foot face was assayed by the writer and gave the following results:

Iron	62.20
Sulfur	0.90
Phosphorus	0.023
SiO ₂	5.60
Manganese	0.39
TiO ₂	Nil

A sample taken from the same place by McConnell assayed as follows:

Iron	62.57
Sulfur	0.403
Phosphorus	0.024
Insoluble matter	6.46

These samples show high sulfur, but it is well to note that all of the ore in this mine is very coarsely crystallized and very friable and, if it were found necessary, could easily be treated by magnetic separation and a concentrate low in sulfides produced with a minimum amount of crushing.

The third open-cut is about 50 feet east and 40 feet lower than the one described above and measures about 60 feet in length by about 30 feet in width and is approximately 35 feet high at the face. The ore here is about the same as that in the second open-cut except that it contains a little more chalcopyrite.

The short tunnel, which is about 20 feet long, that was run in the orebody on the level of the second open-cut is entirely in ore of the same character as that exposed in the open-cut.

The shaft, which was sunk at a point about 250 feet south and 75 feet below the last described open-cut is said to have passed from the surface down through 70 feet of garnet-epidote rock and then through diorite for the remaining distance.

At the bottom of the shaft a tunnel was run northerly with the purpose of intersecting the orebody, which it reached at a distance of about 215 feet. It was continued for about 75 feet into the ore. Before reaching the magnetite, the tunnel cut a vein about four feet in width which carried considerable pyrite, pyrrhotite, marcasite and chalcopyrite. The tunnel was also extended south from the bottom of the shaft until it broke through the surface on the side hill at a point about 300 feet from the beach and 150 feet above sea level. The dis-

tance from the bottom of the shaft to the portal of the tunnel is 475 feet. A sample taken across the face of this tunnel assayed as follows:

Iron	60.30
Sulfur	0.07
Phosphorus	Nil
SiO ₂	7.90
TiO ₂	Nil
Manganese	Tr.

A sample taken along the 75 feet of ore exposed in the tunnel is reported by McConnell to have yielded as follows:

Iron	55.20
Copper	0.14
Sulfur	0.266

The total iron ore above the lower tunnel in the Prescott mine is estimated by McConnell at 1,366,400 tons.

Paxton Mine—The Paxton mine is located about 3,600 feet from the Prescott is a S 81° E direction and is at an elevation of about 450 feet. The main orebody here, like the one at the prescott mine, outcrops in a bold bluff about 60 feet in height. The horizontal projection of the surface outcrop measures about 150 by 300 feet in extent. The occurrence is at a contact between quartz diorite and porphyrite and is bordered on the north side by garnet-epidote-magnetite rock, which extends along the porphyrite-diorite contact northerly for about 500 feet to the tip of a limestone tongue which fills a large "bay" between the two intrusive rocks. It is possible that this limestone tongue formerly extended to the ore body and has been replaced by the garnet-epidote-magnetite rock. The contact with the quartz diorite on the south is quite sharp, very little altered rock being present.

Development work at this mine consists of two open-cuts and a crosscut connecting them, together with a tunnel about 40 feet in length. The diorite-magnetite contact exposed in these open-cuts show the orebody to be nearly vertical. The tunnel was run entirely in solid magnetite.

The ore at this mine is very similar to that at the Prescott. It is coarsely crystalline and contains considerably more sulfides, principally pyrite and chalcopyrite, than the former, at depth. On the surface of the outcrop, however, the sulfides have been leached out, leaving the ore comparatively free from sulfur. A sample taken

from the surface at right angles along the maximum axes assayed as follows:

Iron	65.10
Sulfur	0.05
Phosphorus	0.024
SiO ₂	8.30
TiO ₂	Nil
Manganese	0.36

A sample taken across the face of the tunnel assayed as follows:

Iron	62.60
Sulfur	3.17
Phosphorus	Tr.
SiO ₂	8.80
Manganese	Tr.

An assay taken along the length of the tunnel by McConnell yielded as follows:

Iron	59.40
CuO	0.30
Sulfur	1.07

A sample taken from this same tunnel by Lindeman assayed as follows:

Iron	64.48
Sulfur	1.866
P ₂ O ₅	0.005
SiO ₂	4.47
Copper	0.22
MgO	1.13
CaO	1.32
Al ₂ O ₃	0.66

The statements about the Prescott ore also apply here: the pyritiferous variety is coarsely crystalline and the sulfide minerals can be separated from the magnetite by magnetic separators with a minimum amount of crushing. Close examination of screen-sized material from the sample taken in the tunnel disclosed the fact that the pyrite when crushed to 10 mesh was almost entirely freed from the magnetite.

The ore in this mine is estimated by McConnell at 1,607,200 tons. He assumes that the lens extends downward equal to the exposed surface length. It would seem that this assumption was entirely justified inasmuch as the Prescott orebody has been proved to extend to a depth of at least one and one-half times the length of its surface outcrop and is still very strong on the lowest level.

Lake Mine—On the straight line connecting the Prescott and Paxton mines and about 1,400 feet eastward from the latter is located

the Lake mine. The orebodies here occur at a contact between the end of a tongue of the limestone which projects into the porphyrite. The main orebody is separated from the limestone by garnet-epidote-magnetite rock just as at the Paxton mine and the southern extremity of the lens is marked by a rather sharp contact between the magnetite and the porphyrite. An acid dyke with an east and west strike cuts the orebody, showing that mineral deposition closed before the end of igneous activity.

The altered rock north of the main orebody carries considerable copper and a lens of chalcopyrite ore was mined here some years ago. Lee, the caretaker of the property, states that the copper ore workings cut through a 30-foot lens of very pure magnetite overlain by limestone. The shaft and underground workings were full of water and could not be examined at the time of the writer's visit.

Development work on the magnetite orebody consists of two connected open-cuts which together measure about 100 feet in length by 50 feet in width and expose a face over 50 feet in height, and a short drift about 30 feet long.

The ore in this mine is very fine-grained, quite free from sulfides and of excellent quality. The mine was sampled by taking two samples along the major and minor axes of the surface outcrop. These assayed as follows:

	(1)	(2)
Iron	64.0	63.2
Sulfur	Tr.	Tr.
SiO ₂	6.4	8.2
Phosphorus	Nil.	Nil.
Manganese	Low	Low
TiO ₂	Nil.	....

McConnell reports a rough sample taken from the face in the large open-cut to have yielded 57.5 per cent iron, 0.045 per cent sulfur, and a trace of copper.

Lindeman reports an average sample from this mine as follows:

Iron	59.57
Sulfur	0.137
P ₂ O ₅	0.057
SiO ₂	8.33
Copper	0.08
Al ₂ O ₃	1.71
CaO	3.82
MgO	1.05

The main orebody of the Lake mine has a surface exposure 130 feet wide by 180 feet long. McConnell estimates the amount of ore in this lens at 504,000 tons.

Other Ore Bodies on the Iron Range—There are a great many other magnetite lenses outcropping in the iron range, none of which has had any appreciable amount of development work done on it. The principal deposits, other than those of the three mines described above, consist of three large lenses 800 to 1,000 feet northeast of the Prescott mine, a group of lenses 500 to 800 feet northwest of the Paxton mine, and a series of lenses which outcrop in a long line 1,000 to 2,000 feet south of the Lake mine. These lenses generally speaking consist of high grade ore which is exceptionally free from sulfides.

The three principal lenses northeast of the Prescott mine have the following average dimensions on their surface outcrops: 250 feet by 50 feet; 160 feet by 40 feet; and 210 feet by 80 feet, respectively. An average sample taken lengthwise of the most easterly of these outcrops assayed as follows:

Iron	59.50
Sulfur	0.06
SiO ₂	5.70
Phosphorus	0.031
Manganese	0.30
TiO ₂	Nil.

The largest and most westerly lens is entirely within limestone and is higher grade than this latter one. McConnell estimates the amount of probable ore in these three lenses at 993,600 tons. Their outcrops are 150 to 350 feet higher than the Prescott mine and could easily be mined and the ore transported to salt water by gravity tram.

The group of lenses which outcrop a few hundred feet northwest of the Paxton mine are enclosed in a contact rock which carries a large percentage of magnetite. It is possible that these lenses will be found to be connected beneath the surface, constituting a single ore body. There is a large area of garnet-epidote-magnetite rock here which will probably be mined and milled. A very good concentrate could be obtained.

The series of lenses which outcrop in the long line about 1,000 feet in length south of the Lake mine appear to constitute the vein filling in the fissure in the porphyryite which forms both walls of the deposits. The walls of the vein are well defined and dip nearly vertically. The lenses are all about 10 to 20 feet in width and range

in length from 30 feet up to 220 feet. The ore in these deposits is exceptionally pure and fine grained and breaks in cubes. A fair sample of this ore assayed as follows:

Iron	68.8
Sulfur	Nil
Phosphorus	Nil
SiO ₂	4.0
TiO ₂	Nil
Manganese	Low

A sample is reported by McConnell to have assayed over 69 per cent iron, with no copper and only 0.001 per cent sulfur.

If the theory regarding the origin of the magnetite is correct—namely, that it was derived from the same magma as the quartz diorite—it would indicate that these lenses have considerable extension in depth since no quartz diorite outcrops within five or six hundred feet of the nearest deposit.

Tonnage—The total amount of ore in the Prescott, Paxton, and Lake mines, and in the three lenses northeast of the Prescott ore body is estimated by McConnell at 4,521,200 tons. If the group of lenses northwest of the Paxton mine and those south of the Lake mine are included, this estimate could very reasonably be increased to between 5,000,000 and 6,000,000 tons.

In Bulletin 39A of the United States Geological Survey, page 104, C. W. Hayes says:

Deposits of iron ore of the igneous contact type are known to occur in British Columbia, and those of Texada island have been mined to some extent. These deposits are estimated to contain at least 30,000,000 tons of ore of present commercial grade and probably a considerably larger amount of low-grade and deep ore not now available.

This estimate is undoubtedly high.

Composition of Ores—The results of the assays of the Texada iron ores are consolidated in the following table:

Orebody	Assayer	Fe	P	S	SiO ₂	TiO ₂	Mn	Al ₂ O ₃	CaO	MgO	Cu
Prescott E open-cut	Whittier	61.0	0.017	0.10	6.9	Tr.	0.30	.....	.....	.....	.....
Prescott SW open-cut	Whittier	62.2	0.023	0.90	5.6	Nil	0.39	.....	.....	.....	.....
Prescott SW open-cut	McConnell	62.57	0.024	0.403	6.46	...	.....	.....	.....	.....	.....
Prescott SW open-cut	Lindeman	64.30	...	0.303	.....	...	.....	.....	.....	.....	0.14
Prescott face lower tunnel	Whittier	60.3	Nil	0.07	7.9	Nil	Low	.....	.....	.....	.....
Prescott face lower tunnel	Brewer	66.0	Tr.	Nil	3.3	...	.....	.....	.....	.....	0.14
Prescott lengthwise lower tunnel	McConnell	55.20	...	0.266	.....	...	.....	.....	.....	.....	.....
Average of Prescott	Lindeman	63.27	.006	0.347	4.37	...	.....	1.18	2.58	1.05	0.09
Paxton from surface	Whittier	65.1	.024	0.05	8.3	Nil	0.36	.....	.....	.....	.....
Paxton from tunnel face	Whittier	62.6	Tr.	3.17	8.8	...	Low	.....	.....	.....	.....
Paxton length of tunnel	McConnell	59.40	...	1.07	.....	...	.....	.....	.....	.....	0.30
Paxton average	Lindeman	64.48	0.002	1.866	4.47	...	.....	0.66	1.32	1.13	0.22
Lake surface	Whittier	64.0	Tr.	Tr.	6.4	Nil	Low	.....	.....	.....	.....
Lake surface	Whittier	63.2	Nil	Tr.	8.2	...	Low	.....	.....	.....	.....
Lake face of cliff	McConnell	57.50	...	0.046	.....	...	.....	.....	.....	.....	Tr.
Lake average sample	Lindeman	59.57	0.025	0.137	8.33	...	.....	1.71	3.82	1.05	0.08
Lens south of Lake mine	Whittier	68.8	Nil	Nil	4.0	Nil	Low	.....	.....	.....	.....
Lens south of Lake mine	McConnell	69.4	...	0.001	.....	Nil	.....	.....	.....	.....	Nil
Lens West of Prescott	McConnell	68.2	...	Tr.	.....	...	.....	.....	.....	.....	Nil
Lens NE of Prescott	Whittier	59.5	0.031	0.06	5.7	Nil	0.30	.....	.....	.....	.....
Prescott dump (waste)	Whittier	51.0	...	...	15.4	...	.....	.....	.....	.....	.....

THE VANCOUVER ISLAND DEPOSITS

The writer did not visit any of the iron ore deposits on Vancouver island, and it has been necessary to search various reports in order to present the following descriptions of the various orebodies. The sources of this information include the Reports of the Minister of Mines for British Columbia from 1901 to 1915, inclusive; Memoir No. 13 and Summary Reports of the Geological Survey Branch of the Canadian Department of Mines for 1904, 1909, 1910 and 1915; Summary Reports of the Mines Branch, Department of Mines, Canada, for 1904 and 1909; Iron Ore Deposits of Vancouver and Texada Islands (Bulletin No. 3, 1917, of the British Columbia Department of Mines), by W. M. Brewer, and Bulletin 285 of the United States Geological Survey, by C. K. Leith.

The deposits are described in geographic order, beginning at the south end of the island and proceeding up the west coast and down the east coast. The deposits are all located on or near the coast, none of them being situated more than ten miles inland, with the exception of the two following—the Klaanch river and the Upper Quinsam lake deposits. The former is 26 miles from tidewater by trail, lake and river route, while the latter is about 25 miles by trail from Campbell river, on the east coast of the island.

Nearly all of the deposits on the west coast occur at or near the contact of the coast batholith with the sedimentary formations of the island, and usually with the limestone phase of these sediments. All of the deposits are of magnetite with the exception of one—an occurrence of bog ore on Quatsino sound.

Sooke District

There are several deposits of magnetite in the Sooke district, on Sooke harbor, which is about 30 miles west of Victoria, but most of the ore is so contaminated with sulfur and copper that it is of little or no commercial importance as an iron ore.

Brewer states that the deposits of iron ore in this district belong to the type classified by Clapp as "replacement or segregation deposits in Sooke gabbro." Apparently no deposits of this type have been found which are of much commercial value.

Speaking of the most important deposit in this district, Dawson says:

The deposit is rather of the nature of a stockwork than a true vein, but can be traced for some distance in a northeasterly and southwesterly direction, and in places shows from 10 to 20 feet of nearly pure ore.

Carmichael reports assays running from 49 to 72 per cent iron.

Port Renfrew District

Black Sand—As stated elsewhere, Dr. C. E. Weaver and A. S. R. Wilson made an examination of a supposedly large deposit of black sand which was reported to exist in the vicinity of Lost river, in the Port Renfrew district, with the object of determining, if possible, the probable value of the property as a source of iron ore. The following is Weaver's report:

The area involved in this examination is situated approximately twelve miles east of Port Refrew, a short distance east of the mouth of Sombria river, on the west coast of Vancouver island. At this point there is a coastal bench approximately 500 feet above sea level in elevation. This has been cut into by the Sombria and Lost rivers, as well as by the wave action along the shore of the Strait of Juan de Fuca. These cliffs are situated about 500 feet inland from the present shore line. In the past they have been hydraulically mined for placer gold. The basal beds are schist and Tertiary sandstone, which have no connection with gravels and sands. These two latter rest upon the older rocks in a nearly horizontal position. They consist of sand, light-colored clay, clayey sandstone and poorly cemented gravels containing boulders up to one foot in diameter. There is no field evidence of black sand.

An examination of the exposures does not warrant the supposition that commercial deposits of black sand are available in the particular area investigated.

This was reported to be one of the largest deposits in the Northwest, but is evidently negligible as a commercial source of iron ore.

Black sand is known to occur in varying quantities at many points along the coasts of Oregon, Washington and Alaska. It is very doubtful if such deposits will ever be utilized for their iron ores except as the magnetite sand might be saved as a by-product in the operation of extracting the gold and platinum. It might be smelted in electric furnaces on a small scale at various points along the coast, where such deposits are known to occur. The black sand would have to be agglomerated and would be best adapted to electric smelting in which high quality steel and ferro-alloys are produced.

Magnetite in Place—Extensive deposits of magnetite occur on the Gordon river and also on Bugaboo creek, one of its tributaries. Gordon river empties into San Juan bay on the west coast of Vancouver island about 80 miles from Victoria. The deposits are covered by three groups of claims—the Gordon River group, Bugaboo Creek group, and Conqueror group. These deposits were examined by Charles H. Clapp, whose work was published in the Summary Report of the Geological Survey Branch of the Department of Mines of Canada, for 1909. Mr. Clapp's report is as follows:

On the Gordon river and its tributary, the Bugaboo, which empties from the west into the main river about 6 miles from the mouth, are developed

large bodies of magnetite which have been exploited for iron. These deposits occur in coarsely crystalline limestones near the contact with diorite.

There are several belts—at least five—of limestone, which are separated by diorite. The diorite, which is apparently a peripheral phase of the granodiorite batholith, is intrusive into the limestone, and is itself cut by the granodiorite. The limestones were originally pure, to judge from the large beds of pure white, coarsely crystalline, marble that are found. They have been tremendously altered by the invading batholith, which is to be expected from the fact that the belts of limestone are only 75 to 100 yards wide, and are of the nature of roof pendants. The large one, in which the principal ore deposits are developed, is continuous for at least three miles, having a strike of about N. 70° W. It is parallel to Bugaboo creek and occurs on the southern slope of the Bugaboo valley. The limestone has been in part changed to the ordinary siliceous garnet-diopside rock so characteristic of limestone contacts. Much of it has been more profoundly altered to an amphibolite consisting chiefly of hornblende and feldspar.

The igneous rock itself has apparently been subjected to change. Although the chief rock type of the batholith is granodiorite, no granodiorite has been noted in direct contact with the limestone. The igneous types at the contact are chiefly diorites, some of them monzonite in habit. At the actual contact a very dark diorite occurs, extremely rich in femic minerals. Since this is a feature only of the limestone contacts, it is to be presumed that the limestone had a profound influence on the invading igneous rock.

Along the Bugaboo Creek belt, as well as along the other smaller strips of limestone, large masses of almost pure magnetite have been found. These vary in size up to masses such as are exposed in the Baden Powell claim, which is 125 feet wide and about 500 feet in length on the outcrop. The magnetite, although nearly pure, is cut by great numbers of veinlets of pyrite and chalcopyrite. An average of the three analyses from these deposits, as given by Lindeman, is as follows:

Iron	60.850
Silica	7.300
Sulfur	2.550
Phosphorus	0.048

This doubtless fairly represents the better grade of deposits.

An interesting feature is exhibited at the contact of the magnetite body and the marble, which lies below the marble on Bently creek. Apophyses of magnetite have penetrated the pure marble much as would apophyses of igneous rock an invaded formation. Irregular tongues penetrate and have included fragments of the limestone.

The nature of the deposits is such that there appears little doubt that the batholith must be looked to for the source of the metallic contents. That the metallic minerals, especially the magnetite, were deposited from very concentrated solutions, is strongly suggested by the intrusive veins exposed on Bently creek.

Other deposits of a similar nature are known to occur in the same formation, south of Sarita river, as well as in the more northerly portions of the island.

That the deposits are large and extensive is strongly supported by their occurrence, and by the development work which has already been done. The high percentage of sulfides is extremely undesirable, and will doubtless always be present. However, this is not too high to render the ores unfit for smelting.

Gordon River Group

From Carmichael's report in the Minister of Mines Report for 1902 it is apparent that considerable development work has been done

on the Gordon River group of claims without much success in proving the existence of ore at depth.

Other deposits on Gordon river are reported by Brewer as follows:

Other outcroppings of magnetite occur along the Gordon river on both banks for about a mile, following the contact between the Nitinat marble and plutonic rocks. The work, consisting of trenching at various intervals, shows that the outcroppings are apparently disconnected lenses.

Bugaboo Creek Group

The development work on this group of claims discloses considerable magnetite, according to Einar Lindeman, who examined the properties in 1909. He states that a tunnel 114 feet long has been run into the hill about 90 feet below the contact between the ore and an igneous rock which discloses ore throughout its entire length, with the exception of a diorite dike 8 feet wide about 30 feet from the portal. He reports that an average sample of the ore taken along the tunnel gave the following analysis:

Iron	58.30
Sulfur	2.75
Phosphorus	0.013
Insoluble matter	8.80

Lindeman also reports that another tunnel 114 feet in length was run into the hill about 35 or 40 feet below the first one and that most of the distance it is in limestone and diorite, but the last few feet show magnetite dipping into the hill. Brewer estimates 500,000 tons of probable ore and 250,000 tons additional of possible ore.

The Sirdar claim, which is about two miles up the valley from the deposits described above, is reported to contain considerable showings and sufficient development work has been done to enable Mr. Brewer to estimate 94,000 tons of actual ore and 47,000 tons additional as possible ore. An average sample is reported by Lindeman as follows:

Iron	56.57
Sulfur	2.75
Phosphorus	0.121
Insoluble matter	8.52

Conqueror Group

This group is located on Bugaboo creek and the largest deposit is about 8 miles from San Juan bay. This deposit is crosscut by the creek, which exposes a body of magnetite 40 feet in height. The deposit is said to be of the contact metamorphic type.

Brewer has described this deposit and estimates it to contain 16,000 tons of actual ore, 230,000 tons of probable ore, and 120,000 tons of possible ore. He reports average analyses as follows:

	(1)	(2)
Iron	59.70	62.98
Sulfur	6.16	4.28
Phosphorus	3.08	Tr.
Silica	0.00	0.00

Two other analyses, the first by Lindeman, and the second by Carmichael, are reported as follows:

Iron	67.09	69.20
Sulfur	1.60	0.50
Phosphorus	0.009	.....
Silica	4.51	2.70

Barclay Sound and Alberni Canal Deposits

Barclay sound is a body of water embracing between two and three hundred square miles and producing a very marked indentation of the west coast of Vancouver island at some 90 or 100 miles from its southeastern end. At its head this sound is constricted to a narrow inlet which penetrates the island for about two-thirds of its width. This long narrow arm is known as Alberni canal.

At various points along the slopes bordering this sound and its tributaries are extensive deposits of magnetite which, because of their extent and favorable location for transportation facilities, are very important.

Along the southern slope of the Broughton range of mountains, which border Sechart channel on the north, are a number of outcrops of magnetite which occur at elevations above 700 feet.

These deposits are covered by a number of crown-granted claims. The names of the claims, according to Brewer's report, are as follows: the Crown Prince; Victoria; Old Ireland; Bald Eagle; Iron Chief; Standard No. 6; Lord of the Isles No. 4; Emily R.

Brewer says:

The most important deposits of magnetite occur on the Crown Prince, Lord of the Isles, and Bald Eagle mineral claims, where the most development work has been done. These occurrences belong to the contact-metamorphic type, in which the ore lies between crystalline limestone and horn-blende igneous rock, colored in various tints of green.

Crown Prince—According to Carmichael's report to the Minister of Mines, the Crown Prince is the most easterly claim upon which much work has been done. He says it is located at an elevation of

1,600 feet and is two miles from the beach at Sechart by trail. Brewer says, however, that from deep water in Canoe pass the distance is considerably less.

The surface showings consist of a conical bluff 70 feet high and 75 feet wide at the base. Upon one side is exposed a body of magnetite with an apparent width of 35 feet, having a southeasterly strike and a southerly dip of 45 degrees. To the north of this bluff some stripping and trenching has exposed considerable magnetite which may be found to be an extension of the first orebody.

Part of Brewer's report is as follows:

The most extensive outcroppings of magnetite occur in a prominent ridge where wide bands of magnetite are exposed alternating with bodies of green igneous rock, much sheared, altered, and schistose near the magnetite. The strike of the bands of magnetite is southeastward, the dip being 45 degrees southward.

The face of the ridge is stripped about 200 feet long by 70 feet high up the slope about 45 degrees, exposing magnetite mixed with country rock in the banded structure for 70 feet along the ridge, then country rock for 100 feet, then magnetite for 33 feet.

Carmichael states that about 15 feet below the base of the bluff a tunnel has been driven into the hillside in an endeavor to crosscut the orebody. Seventy-five feet was driven before the ore was struck in the main tunnel. The remainder of the tunnel to the face, some 18 feet, is in solid magnetite. Brewer, speaking of this tunnel, says:

This was driven through about 50 feet, where a narrow seam of calcite occurs, followed by a body about 10 feet wide of arsenical pyrite, mixed with iron pyrite and magnetite, which changes to a mixture of magnetite and green country rock, then to solid magnetite and through which the adit is driven nearly 20 feet to the face, and was still in ore.

From a point 50 feet in from the portal a drift has been driven to the left for about 70 feet, making an angle of about 45 degrees with the main tunnel. The first 20 feet of this drift is in ore somewhat mixed with rock. The next 20 feet is in magnetite and country rock, with much iron pyrites in evidence. Brewer states that the last 34 feet of the branch or drift is apparently under the magnetite exposed in the main adit, as the dip of that body is 45 degrees to the southward, or to the right of the opening. An average sample across the face of the main tunnel is reported by Brewer to have assayed as follows:

Iron	56.60
Sulfur	0.72
Phosphorus	Nil.
Silica	19.00

He also reports average samples taken along 28 feet on the left side of the branch adit as follows:

Iron	54.4	55.6
Sulfur	1.4	0.4
Phosphorus	Nil	Tr.
Silica	21.2	17.6

Carmichael reports an average sample of this ore as follows:

Iron	48.4
Sulfur	0.7
Phosphorus	Tr.
Titanium	Tr.
Copper	Nil

Lindeman reports an assay from the same workings as follows:

Iron	48.06
Sulfur	0.623
Phosphorus	0.006
Insoluble matter	23.22

These assays do not disclose very good ore, the iron content being rather low for magnetite and the silica being high. From the various descriptions of the orebody as well as the assays, it appears that the deposit as a whole has a high sulfur content, but it is probable that a good shipping product could be obtained by hand sorting.

Evidently an accurate estimate of tonnage available is impossible owing to insufficient development work. Brewer roughly estimates 75,000 tons of actual ore, with an additional 200,000 tons of possible ore.

Lord of the Isles—This claim, according to Brewer, is about 2,000 feet west from the Crown Prince and shows magnetite outcrops on the face of a precipitous bluff at about 850 feet elevation. The magnetite is said to be a contact deposit between green hornblende igneous rock and crystalline limestone, very irregular and apparently not of very great lateral extent, although it is possible that larger orebodies exist in depth. Development work consists of 97 feet of tunneling and a winze of unknown depth. Brewer states that the work done so far is insufficient to justify any estimate of tonnage. He reports that a grab sample from the dump assays as follows:

Iron	50.4
Phosphorus	Tr.
Sulfur	2.5
Insoluble matter	10.6

This deposit is apparently of not much importance.

Bald Eagle—The Bald Eagle claim joins the Lord of the Isles on the west. Outcroppings of magnetite are said to occur on the face of a steep bluff at an elevation of 1,000 feet. Brewer describes this deposit as follows:

This outcrop measures about 75 feet long by about 50 feet up the slope of the bluff at the widest point. The occurrence of magnetite has the appearance of a blanket covering the light-colored igneous rocks that form the bluff. An adit is driven 72 feet into the bluff under the outcropping, about 40 feet vertical measurement below the top, and at the face a drift is driven 45 feet to the right. No magnetite is exposed by this work, which confirms the blanket-structure theory, but farther up the mountain there is a contact between crystalline limestone and igneous rock, similar to that underlying the magnetite on the face of the bluff, and at the contact an outcropping of magnetite occurs, but apparently not of sufficient extent to be of importance.

A sample from the bluff assayed:

Iron	60.7
Sulfur	Tr.
Phosphorus	Tr.
Silica	13.6

The report of the Minister of Mines for 1902 states that considerable pyrite is mixed with the ore.

Western Steel—This claim joins the Bald Eagle on the north at an elevation of 1,200 feet. The surface showings on this claim are reported as largely the same as those on the Bald Eagle.

None of these claims has been developed sufficiently to expose any large deposits of iron, but the showings should justify further investigation, especially in the light of the fact that the ore could be mined and transported to a deep water harbor very cheaply.

Sarita River—The Sarita river flows into Barclay sound from the east at a point 15 miles from the ocean and directly opposite Copper island. At a point about $\frac{1}{4}$ mile back from the river and one mile from its mouth is a long, low ridge, 60 to 150 feet high, running approximately parallel with the river and terminating at its western end in a bluff which rises out of a swamp. The face of this bluff for its full height, or 60 feet, and a width of 92 feet, shows solid magnetite of good quality. Development work consists of a tunnel and drifts run in from the face of the bluff and along the contact between the orebody and the limestone on the south, together with open-cuts and pits which have exposed ore at intervals of 100 to 200 feet for a distance of about 1,000 feet along the top of the ridge. The tunnel has exposed two sides of the first orebody which, according to Carmichael's estimate, contains 30,000 tons of ore running over 60 per cent iron, low in silica and sulfur, only a trace of phosphorus and no titanium. An estimate in the same report places the amount of ore ex-

posed along the top of the ridge at 25,000 tons of iron ore, 50 per cent or over. It is entirely possible and quite probable that much larger orebodies may be exposed with further development. Part of Brewer's report on the Sarita river deposits is as follows:

An open-cut 10 feet deep by 120 feet long has been made across a part of the ridge, exposing diorite on the south side, next magnetite, 62 feet wide, then crystalline limestone, 12 feet wide, then magnetite 45 feet wide, to limestone wall. In this deposit the magnetite is good grade, and the impurities found associated with the ore in the bluff overlooking the river are lacking. The gangue material is garnetite.

The adit is 260 feet long, including all of the crooks; it is driven in solid magnetite, along limestone wall for 111 feet, when diorite is exposed; the adit was continued 18 feet in diorite, but where the magnetite disappeared a turn is made to the left and the adit continued through magnetite 76 feet, with diorite on the southeast side. About 40 feet from the turn diorite shows in the roof, with magnetite underlying it. Gradually the magnetite wedges out; at 76 feet from the turn it practically disappears, except in the floor. At this point the course of the adit is again changed, to the southeast, and driven 60 feet through diorite to the face.

A winze full of water, said to be 7 feet deep, and sunk in magnetite is located 28 feet from the portal of the adit. The body of the magnetite in the bluff is 92 feet wide by 60 feet high above the adit level. Climbing the bluff, the elevation of the ridge increases to the east to about 150 feet above sea level. Test pits and trenches that were examined show magnetite in several places for about 1,000 feet eastward. There is a possibility that the deposits to the east from the long adit are connected and form a continuous ore body.

A sample from the dump at the portal of the adit assayed:

Iron	63.80
Sulfur	0.55
Phosphorus	Tr.
Silica	4.20

A sample reported by Carmichael from the same dump assayed:

Iron	63.70
Sulfur	0.30
Phosphorus	Tr.
Silica	3.85

A sample reported by Lindeman from the same dump assayed:

Iron	60.89
Sulfur	0.76
Phosphorus	0.004
Insoluble matter	3.81

The Sarita river ore is of very good quality and could be mined and transported by surface tram to deep water at a low cost. The property is designated as the Sarita iron mine.

Copper Island—Copper island is the largest island in Barclay sound. It rises to an altitude of 1,000 feet at its highest point. The Copper Island group of mines is located about $\frac{1}{4}$ mile back from the central part of the east coast of the island and at an elevation of about 700 feet. This group of claims comprises the Mountain, Barclay, Clifton, Charmer, Pilot Fraction, Rainbow and Sunbeam, the first of which is the most important.

A large deposit of magnetite, which occurs as irregular masses in garnetite rock, has been exposed by surface stripping, open-cuts and pits on the Mountain claim. The largest deposit, which is some 40 feet wide by 70 feet long, has been developed by two open-cuts, aggregating 85 feet in length, a tunnel 27 feet long, a shaft 12 feet deep, and several shallow pits. Development work so far indicates that the deposit is quite extensive laterally, but shallow in depth. The following description of the orebodies is taken from Carmichael's report in the Minister of Mines Report for 1902. Speaking of the largest deposit, the report states:

It would appear here(and this is strengthened by other investigations further up the hill) that there is, lying on the surface, a zone of greenish country rock, apparently resting on a very similar rock. This zone is shown in places to be 20 to 30 feet thick, while in others it is only a few inches thick. In it there occurs magnetite in the shape of masses, showing defined sides and angles of lenses and stringers, with often sheets a sixteenth of an inch thick; but all of this magnetite, whether in large or small masses, is practically clear mineral. The appearance presented by this mixture of ore and rock can best be described by quoting from Kemp's Ore Deposits (page 63): "The concentration of the magnetite seems to the writer best explained by its settling in the still molten mass until it formed considerable aggregates. When once these rich aggregates have formed they may, in the process of eruption or intrusion, take almost any place in the resulting rock.

The occurrence of the ore on this hill has the appearance of a partially solidified magnetite aggregate, caught up and included in a volcanic flow, which might have been an overflow or an intrusion and which has since been subjected to great flexure and faulting, with subsequent denudation, arrested at the present point by the durability of the magnetite, and leaving the surface of the hill, as it is now, practically coated with magnetite, in some instances not one-sixteenth of an inch thick, and in others several feet. The proportion of magnetite in various parts of the rock varies very much, and where a notable amount is present it is indicated by a knoll on the brow of a ridge. There is no limestone now visible in the vicinity of this magnetite exposure, but such does occur on the same range of hills about $\frac{1}{4}$ mile to the northward, and forms the greater portion of the north end of Copper island. The geology of this island is quite in keeping with the description given of that of Vancouver island in general. Numerous dykes were noted which seem to be of more recent date than the ore deposits, although this is not clearly demonstrated.

Of probable ore there is undoubtedly a considerable quantity over the exposed area. However, but a small percentage could be mined to run 50 per cent iron, without concentration. If, on the other hand, crushing and magnetic separation were resorted to, many thousand tons of rocks carrying from 20 to 30 per cent iron, are available, and would give a con-

centrate of from 60 to 65 per cent iron. From the development done, it is impossible to make any calculations as to the cost of mining and handling such an ore body, and it is consequently equally impossible to say how much ore can be obtained from here and handled at a commercial profit.

Brewer describes in detail the development work on the Copper Island deposits. He says:

It is absolutely impossible for any engineer to make an estimate of tonnage in these deposits; there may be 20,000 tons or even 100,000 tons of possible ore.

Three samples, the first by Brewer, the second by Carmichael, the third by Lindeman, from these deposits assay as follows:

Iron	56.2	50.4	52.00
Sulfur	1.3	0.3	0.23
Phosphorus	0.0	0.033	0.025
SiO ₂	17.0	18.6	16.52

From the descriptions it seems that this ore would be very amenable to magnetic separation and if sufficient ore of this character is developed in the vicinity of Barclay sound and Alberni canal to justify building a concentrating mill, in all probability an excellent concentrate could be produced at a moderate cost.

Anderson Lake—Anderson lake, which is 11 or 12 miles long and about 1½ miles wide, flows into an arm of Barclay sound near its east end through a channel some 200 yards in length. According to the report of the Minister of Mines, considerable work would have to be done on this channel in order to permit the passage of ore-laden scows from the lake to the sound.

On the west side of Anderson lake, about 7 miles from the outlet, at a point some 200 yards back from the shore and 100 feet above it are several outcrops of magnetite. Also, on the face of a bluff some 250 feet higher up other outcrops of magnetite occur which have a lateral extent of about 250 feet. These deposits are covered by Iron Mountain mineral claims Nos. 1, 2, and 3. Here, as in the case of most of the iron deposits on the west coast, no development work has been done. The Minister of Mines' reports give the average analysis of several samples as follows:

Iron	55.7
SiO ₂	20.3
Sulfur	0.3

The silica content could probably be reduced easily by magnetic concentration.

Maggie Lake—Magnetic creek runs into the north end of Maggie lake, which is three miles long by two miles wide and empties into the

western channel of Barclay sound, through Maggie river, which is one mile long.

At a point 100 yards back from Magnetic creek and about 4 miles from its mouth a rather remarkable magnetic attraction is reported by the Minister of Mines. The magnetic attraction is said to be strong over a considerable area. No float or exposure of ore has been found, the bed rock being covered with a sandy loam.

Alberni Canal—About $\frac{1}{4}$ to $\frac{1}{2}$ mile back from Smith's Landing on Alberni canal and at a slight elevation are considerable showings of a good grade of magnetite. Some surface quarrying and several small crosscuts have exposed a face of ore 60 to 90 feet in length by 10 feet in width with a north and south strike and apparently dipping into the hill to the east at an angle of 45 degrees. The orebody is said to consist of clean magnetite which is well defined by diabase walls. An approximate average sample of the ore on the dump is reported by Carmichael as follows:

Iron	55.9
SiO ₂	16.0
Sulfur	1.0
Copper	0.0

Carmichael states that the facilities for cheap mining and transportation here are all that could be desired and the supply of timber and water is unlimited. Lindeman used a magnetic dip needle and reports:

No magnetic attraction could be noticed north of the ore outcrop, but the attraction was strong south of it for a distance of about 70 feet.

Brewer states that the deposit appears to fill a fissure in diorite and that no limestone was observed in diorite within half a mile of this point. An average sample of the ore dump gave the following analysis:

Iron	50.96
Phosphorus	0.004
Sulfur	0.083
Insoluble matter	25.95

This deposit seems to be quite important. The land is covered by locations known as the Darby and Joan mineral claims.

A considerable amount of stripping is said to have exposed a very large surface deposit of magnetite on the Defiance and Defiance No. 1 mineral claims, which are located on the northwest side of Alberni canal at an elevation of 1,000 feet or more and some 4,000 feet on an air line from tide water. The ore could be easily transported to salt water by an aerial tram.

Following is a description of the Defiance group of iron mines, as reported by A. L. Smith, gold commissioner for the Alberni mining division, in 1902:

On the Defiance group, situated on the west side of Alberni canal about 1 1-4 miles from tidal water, at an elevation of 900 feet there are outcrops of magnetite, an average sample of which assayed 63 per cent metallic iron. One outcrop has been traced for 350 feet in a direct line, varying in width from 3 to 10 feet. The iron shows from the surface to a depth of 12 feet, and has every indication of greater depth. Another outcrop appears to be about 30 feet wide and 50 feet in length. A considerable amount of stripping has been done, but these claims have not yet been sufficiently prospected to show the thickness of the ore.

On the Linnet group, situated near Uchucklesit harbor, an outcrop about 40 feet wide, traceable for some 300 feet, has been discovered.

According to Brewer, these deposits occur in lens-shaped bodies between crystalline limestone and an igneous rock. He does not attempt to estimate tonnage, as he says it is impossible to make even a shrewd guess. He reports analyses as follows:

Iron	52.6	66.0	65.8
Sulfur	4.2	Tr.	2.2
Phosphorus	0.0	0.0	Tr.
Silica	12.1	3.3	4.8
Copper	3.3	0.0	0.2

Some of the ore in these deposits is apparently so high in sulfur and copper as to render it unfit for smelting in an iron blast furnace. There is evidently an extensive deposit of magnetite of excellent quality which will require considerable development work before any accurate estimates of tonnage can be made.

Henderson Lake Deposits—At a point on Henderson lake some 10 miles from Uchucklesit harbor, which is at the entrance to Alberni canal, a deposit of magnetite of unknown extent has been exposed by open-cuts. Brewer's report on this property is as follows:

About 250 feet from the lake shore and about 100 feet higher elevation, on the south side of a small creek, a continuous deposit of magnetite is exposed by open-cuts for a distance of 130 feet along the precipitous bank of the creek. Apparently this exposure is across the ore body, which strikes northwest or nearly parallel with the lake shore, and dips 63 degrees to the northeast. The outcroppings of magnetite can be traced about 30 feet down the creek bank nearly to water level, but no continuation of outcroppings is seen across the creek on the north side.

Only a very rough estimate of tonnage of available ore can be made. The writer estimates the actual ore at 20,000 tons and the possible ore at 280,000 tons.

The mountain rises very abruptly on the south side of the creek, and outcroppings of magnetite occur about 250 feet higher elevation than the open-cuts, but no work has been done. An average sample assayed:

Iron	50.00
Sulfur	0.24
Phosphorus	0.00
Silica	22.00

Uchucklesit Harbor Deposits—Magnetite iron ore occurs at several points near Uchucklesit harbor. The only deposit which, judging from available reports, is of any commercial importance as an iron ore is covered by Black Prince No. 2 claim.

The magnetite, according to Brewer, occurs in close proximity to mineral deposits containing much pyrrhotite and is not a contact metamorphic deposit. One of these lenses contains ore of very high grade and excellent quality. Brewer estimates 15,000 tons of actual ore and an additional 15,000 tons of possible ore. Resources available for mining are reported as excellent with a very good opportunity for installing transportation facilities.

Conclusions on Barclay Sound and Alberni Canal Deposits—It is evident that the total tonnage of magnetite ore in the various deposits bordering Barclay sound and Alberni canal is large. It is too contaminated with sulfur and copper or silica to be desirable as a blast furnace material in the raw state. The impure ores here, however, should not be difficult to concentrate into desirable products. A mill could probably be designed which would handle all of the impure iron ores from this district. Mining would be, for the most part, by open-pit and mill-hole methods and should not be expensive. Transportation costs to the mill would be low, as would also the costs of transporting the ore and concentrates from the mill and mine to the blast furnace. If a water route seemed most practicable it would be necessary to employ large vessels since weather conditions on the west coast of Vancouver island do not permit of barge traffic. A large part of the ore could be shipped directly to the blast furnace without preliminary treatment; some would require hand picking; some could probably be handled very easily and cheaply by cobbing machines; and the remainder would require concentration.

It is probable, therefore, that the Barclay sound deposits will be quite important when an iron and steel industry is established in the Northwest.

Kennedy Lake District

Magnetite deposits occur on the Iron Mountain and Chieftain claims, which are situated about three miles northward from the head of Kennedy lake and twelve miles northwest from the head of Henderson lake.

Outcrops of ore are reported at several points, but apparently so little development work has been done that the extent of the deposits is entirely unknown. A sample of ore from the Chieftain, as reported

by Brewer, discloses very low grade ore. On the other hand, a sample from the Iron Mountain claim, as reported by Lindeman, assayed 63.07 per cent iron and was low in impurities.

Hesquiat Lake District

Hesquiat lake is situated a few miles south of Nootka sound and is a short distance from the harbor of the same name, into which it empties through a short stream.

Magnetite deposits are reported to exist on both sides of this lake and less than a mile back from the shores of the lake. The properties on the east side of the lake are known as the Agnes No. 1 and No. 2 claims and that on the west side as the Violet mineral claim. Carmichael describes the deposits in the Minister of Mines' Report for 1902. Magnetite outcrops, "a few yards in extent only," are exposed in the banks of a small creek on the Agnes claim at a point some 4,000 feet back from the lake shore. The deposits occur on a contact between limestone and an eruptive rock.

The outcrops of the Violet claim are located about one-quarter of a mile back from the west shore of the lake. These deposits are also said to lie on the lime-diabase contact. Describing the principal deposit, Carmichael says:

Here there is an exposure of magnetite some 15 feet wide, developed by an open cut into the hillside, 12 feet long and about 4 to 5 feet deep at the face, showing up very clean and solid ore, a sample of which taken for assay gave 59.8 per cent iron; 11 per cent silica; 0.55 per cent sulfur and no copper.

Nootka Sound

According to the Minister of Mines' Reports for 1902 and 1903 and Brewer's report (1917), there are large and promising magnetite deposits on Head bay, at the upper end of Tulpana arm of Nootka sound, which is a long inlet on the west coast of Vancouver island.

The property consists of three claims, the Glengary, Stormont and Fido. The orebodies consist of deposits of magnetite roughly lenticular in shape, which vary in width from 7 feet to 55 feet and which have been traced at intervals for 1,800 feet along a contact between limestone and diabase, according to the Minister of Mines' Report for 1902. Brewer, however, states that the intrusive rock is diorite. Following is a part of his report:

Magnetite deposits occur along the ridge, of the contact metamorphic type, lying between crystalline limestone and diorite. Garnetite is the only gangue material associated with the magnetite in any appreciable quantity.

Open cuts and stripping along the north slope of the ridge have exposed solid masses of magnetite which can be traced in a nearly continuous

line for several hundred feet, and varying in width from 7 to 55 feet. Some of the open-cuts are about 20 feet high at the face, and stripping, in some places, exposes magnetite outcroppings extending downwards from the summit to near the base of the ridge for a continuous length on the incline of about 200 feet, and a maximum width of 40 to 55 feet.

A general sample representing about an average of the deposits assayed:

Iron	56.8
Sulfur	0.1
Phosphorus	Tr.
Silica	1.6

Lindeman reports a sample from this property that assayed:

Iron	66.17
Sulfur	0.017
Phosphorus	0.016
Silica	6.10

Apparently the quantity of magnetite on these claims is exceptionally large. Considering the exposures seen by the writer, and estimating from approximate measurements, he figures that he is safe in placing the tonnage of actual ore available for quarrying at 250,000 tons, with an additional 250,000 tons of probable ore and 750,000 tons of possible ore that may be exposed by further development work. The deposits are very favorably situated to insure mining and transportation at a minimum cost.

Brewer states that no work has been done on the Fido claim by which actual ore can be measured. However, the estimates he makes are 50,000 tons of probable ore and 200,000 tons of possible ore. The proximity of these ores to tidewater, being located about $\frac{3}{4}$ mile from the bay and at an elevation of 800 feet, and their apparently great extent and excellent quality makes them one of the important deposits in the Northwest.

The Klaanch River Deposits

The Klaanch river flows into the south or upper end of Minpkish lake, which is about 15 miles in length, and empties into Broughton strait, opposite Alert bay through Minpkish river. Alert bay is on a small island between Vancouver island and the mainland and about 180 miles northwest of Vancouver.

Extensive deposits of magnetite occur on the Klaanch river at a point about seven miles from its mouth, according to Brewer. This property was visited by Lindeman in 1907, who made a magnetic survey of the deposits. Part of his report, which was published in Bulletin 47, Mines Branch, Department of Mines, Canada, is quoted here as follows:

The claim of most interest is the Iron Crown mineral claim. An exposure of magnetite extends along the river bank face for some 150 feet. The height of the bank is about 80 to 100 feet, forming at some points cliffs of magnetite 25 to 30 feet high. A sample of the ore gave the following analysis:

Iron	64.23
Sulfur	0.233
Phosphorus	0.010
Insoluble matter	4.12

Farther up the hill, about 600 feet from the river several outcrops of magnetite occur along the ridge. An average sample of these gave the following analysis:

Iron	63.89
Silica	5.30
Alumina	1.74
Lime	0.80
Magnesia	1.86
Copper	Tr.
Sulfur	0.017
Phosphorus	0.37

As the dip needle showed a very strong magnetic attraction in several places, it was found advisable to make a magnetic survey and get some information in regard to the extent of the ore bodies.

The report further describes the results of the magnetic survey as follows:

The map shows three separate deposits or groups of deposits, which, for reference, have been numbered I, II, and III.

No. I outcrops on the river bank as stated. The top of the bank is covered with soil and no work has been done to ascertain the width of the deposit; but to judge from the magnetic curves and outcrops available, the width at the west end may be estimated at not less than 100 feet. The length of the ore body may be estimated to be about 190 feet.

Group II is the most important and may be assumed to consist of two and possibly three ore lenses, not counting the small pockets in the northern part of the group. The largest of these lenses has a length of at least 380 feet, a width of 60 feet is very probable, and in some places it is even greater.

Group III is altogether covered by soil. The magnetic curves show, however, the ore strikes to be about parallel with the former group, with a length of about 480 feet, and a width which, in places, may be assumed to be very little less than that of the former. In regard to the depth of the different ore lenses, no conclusion can be drawn from the magnetic map; but as far as surface indications go the claim may be said to be one of the best iron prospects on Vancouver island, and well worth further development.

Apparently these deposits are quite extensive and the ore of excellent quality.

The writer spent about a month around the upper end of Nimpkish lake in the fall of 1912. Nimpkish river is not navigable except for canoes and the cost of making it so would be prohibitive. Consequently the ore would have to be transported down the Klaanch river to the head of Nimpkish lake by rail or surface tram, down the lake by scows, and thence about four miles by rail to tidewater unless it is possible to build a railroad the entire distance from the mining property to Broughton strait or some point on Johnson strait. A road between five and six miles in length could be built over a route between the lower end of Nimpkish lake and Beaver cove with a maximum grade of perhaps three per cent. The body of timber around the head of Nimpkish lake is one of the finest in British Columbia and a road to tidewater would therefore have ample support if logging and mining operations were started simultaneously.

West Arm, Quatsino Sound

Bog iron or limonite occurs at a point about one mile west from Coal harbor, on the west arm of Quatsino sound, and also at a point two miles back from West Arm and several miles further west. The first of these deposits is said to be the most important. This is covered by the Sunrise group of claims.

Brewer says that the ore deposits occur in and border on swampy basins, and on the ranges of a side hill sloping at an angle of about 20 degrees and is said to have considerable lateral extent. This ore has evidently been deposited from solutions heavily charged with ferrous salts, which have been derived from the country rock at higher elevations through the oxidation, decomposition, alteration and leaching out of the pyrite and ferro-magnesian minerals contained therein. These solutions have run down the slope and deposited limonite over a considerable area.

Following is part of the report of the Provincial Mineralogist in the Minister of Mines' Report for 1907:

The claims extend to the edge of the arm, and at a point about a quarter of a mile from the water a deposit of bog iron ore of excellent quality has been discovered, covering the surface over a considerable area. From the workings visible it would appear that the iron deposit over an area 300 feet long and 200 feet wide had been removed from the surface down to solid bed rock, and this area had yielded 1,500 tons of ore, which had been shipped. The work done showed the deposit of bog ore to be on a side hill, which sloped at an angle of about 20 degrees towards the sea, lying on a smooth, water-worn bed rock to a depth of, in some places, 4 feet, and in others, of as many inches; the average thickness of the deposit was not over 24 inches. Large trees and brush had been growing on top of the deposit, the roots being all through the ore, greatly increasing the cost of extraction, which, under the circumstances, must have been excessive. The superficial area over which the deposit shows is considerable, but no prospecting that has been done proves it to be of a greater average depth than at the point where its extraction was attempted.

Prince's Iron Claims. A few miles to the west, along the shore of the arm, a trail leads inland to the north for a couple of miles, to what is known as Prince's Upper Claims, a group of claims, the number and names of which could not be ascertained. The open-cuts were seen, and of these the one in which the most promising showing occurred started from the creek bed and ran up the face of its gently sloping bank, showing in nearly horizontal layers, first, 4 feet of bog iron ore; next, 1 foot of gravel with a layer of fine kaolin clay on top; next, 9 inches of iron ore; then 2 feet of ochre and clay, above which was the black surface mould. A similar showing was seen in another cut about 150 feet farther up the creek, and these may be taken as typical of the more successful strippings made. There is, undoubtedly, a very considerable area covered with iron ore, but, so far as could be seen, its depth had not been demonstrated further than described. Samples were taken from the lower 4-foot deposit of ore, and upon assay gave 48.12 per cent, 48.31 per cent and 50.19 per cent of iron, with much organic matter. The ochre and clay stratum assayed 36.6 per cent of iron.

The deposit near Coal harbor is apparently ore of a very good quality. Analyses of average samples are reported by Lindeman as follows:

Iron	54.46	56.97
Sulfur	0.15	0.447
Phosphorus	0.038	0.038
Insoluble matter	2.32	1.40

Timber and water are plentiful. Transportation would be by water down the west coast of Vancouver island and should not be expensive. Although mining would be carried on by open-pits or stripping, the deposits are apparently so shallow that very low costs could not be expected to be attained. The ore is of such quality as to make a very desirable material to mix with the magnetite of southern Vancouver island and Texada island. For this reason these deposits will probably claim some attention.

Upper Quinsam Lake

Upper Quinsam lake is located at some eighteen miles on an air line southwest from the town of Campbell River, on the east coast of Vancouver island. It is drained by the Quinsam river, which empties into Campbell river near the mouth of that stream.

According to several of the annual reports of the Minister of Mines, it was known that deposits of magnetic iron ore occurred near this lake, but little was known of their extent, except that it was reported that the orebodies covered large areas, until Brewer examined the property in the summer of 1916. As his is the only detailed report at hand, it is here quoted in full:

Numerous large outcroppings of magnetite occur on the north slope of a mountain about half a mile south from the south end of Upper Quinsam lake, at elevations from 220 to 560 feet above the lake. These outcrops occupy a zone striking almost due east, and expose deposits that are representatives of the contact metamorphic type, with magnetite lying between limestone and diorite, dipping 80 degrees north. The occurrences are found distributed within an area measuring about 1,000 feet wide north to south by 1,200 feet east to west, and while unbroken continuity is not shown between the various outcroppings on the surface, yet there are so many that it is almost excusable to consider them as belonging to one deposit until the contrary is proved.

At 240 feet elevation above the lake there is an adit 135 feet long, driven into the mountain side southward in magnetite the entire distance, and with magnetite in the face, but somewhat mixed with country rock and garnetite. The side hill rises at an average angle of 44 degrees, but over the face of the adit the slope is steeper, so that there are about 195 feet backs.

An average sample from the dump assayed: Iron, 58.6 per cent; sulfur, trace; phosphorus, trace; silica, 9.3 per cent.

The adit is projected to cross-cut the mineralized zone at the point where it is about 800 feet north to south. According to a topographic survey, this adit is driven under several outcroppings of magnetite, and the projected face is 320 feet vertically under the farthest outcrop south of the portal.

Other work on the property consists of open-cuts and surface stripping to the east and south from the adit, and at various levels above the 240 or adit level, which openings expose a large number of outcroppings of clean magnetite. The most extensive occurs about 1,000 feet southeastward from the adit on the 400-foot level; this measures about 100 feet across and is almost square.

It is impossible to form any reliable estimate of the tonnage of ore available from measurements made where work has been done because of insufficient data. There is no question but that a very large quantity of magnetite can be quarried for immediate shipment. The contour of the mountain side is such that the ore can be mined with steam shovels, in a manner similar to that in use in the low-grade copper-ore mines in Utah, and the large quantity of ore exposed in surface outcroppings alone is evidently sufficient to suggest this method for mining operations.

In the floor of the adit on the 240-foot level the orebody is quite as strong as on the surface, and there is every indication that it maintains its continuity to an undetermined depth below this level.

A reputable mining engineer of Vancouver, British Columbia, spent some time several years ago examining iron ore deposits of British Columbia and he informed the writer that, in his estimation, certain magnetite deposits—undoubtedly those described above—gave promise of being the largest deposits of their kind in the northwest, not excluding the Texada island deposits.

Brewer does not attempt an estimate of actual or probable ore, but he places the amount of possible ore at 5,000,000 tons, which is greater than any other magnetite property reported in the northwest. Although the actual extent of the deposit is unknown, it is apparent that there is a large tonnage of first class ore here which could be mined at a low cost. This property may prove to be one of the most important iron properties in the Northwest.

Conclusions on Vancouver Island Deposits

The total tonnage of the Vancouver island deposits is undoubtedly large, and probably approaches that of all other iron ore reserves in British Columbia which are near enough to the coast to be of any immediate importance as a source of ore for a blast furnace located on tidewater. Further exploration and prospecting are necessary in order to prove the extent and continuity of the deposits.

The ores are, as a rule, quite pyritiferous. Many will require beneficiation before smelting, while others can be utilized directly. Some are very high grade and exceptionally pure. Conditions surrounding the deposits are, in general, favorable for cheap mining and transportation. Water power can usually be easily developed in close

proximity to the ore deposits, while timber is invariably present in large quantities. In some cases the exploitation of the timber and ore deposits might best be carried on simultaneously in order to obtain the most economical results.

LOUISE ISLAND DEPOSITS

Location and Description

The Louise island iron property is located about two miles from the north shore of Louise island, one of the Queen Charlotte group, which is separated from Morsely island by Camshewa inlet. The nearest port of call for the Canadian Pacific steamer, which runs to the Queen Charlotte islands, is Queen Charlotte City, which is situated on Skidegate inlet, about thirty miles north of Camshewa.

The orebody is a deposit of magnetite, impregnated in places with pyrite and marcasite, with a siliceous gangue of porphyrite, and presumably occurring as a replacement of porphyrite and limestone, although no limestone was found in actual contact with ore. Limestone is exposed, however, in one of the most southerly pits which was sunk through the surface soil at a point not very far from the southern edge of the orebody. The ore is surrounded by an aureole of typical contact minerals, comprising the contact rock which is very similar to that occurring around the orebodies of Texada island, and referred to by R. G. McConnell as garnet-epidote rock. This altered rock is also often scattered through the ore in bunches and irregular shaped masses. The gangue rock contains a large proportion of quartz, as well as garnet, epidote and amphibole.

The development work on this orebody consists of some 25 or 30 open-cuts, which are usually little more than small pits sunk through the surface moss and drift, often not reaching to bed rock, together with a tunnel 47 feet in length, driven near the lowest point of the outcrop. There is one open-cut about 60 feet above the tunnel, which is about 20 feet in length by about 10 feet in width and exposes the ore to a depth of 10 feet at the face. Another open-cut immediately below the tunnel is of about the same dimensions. The tunnel has been driven along a slip zone. At the face of the tunnel there is an exposure, 2 feet wide, of hard unaltered magnetite, containing much specular hematite. This is cut off on the right hand side by a slip-plane which has nearly a vertical dip. A drift was started to the right at the face and was run for about 8 feet in soft, iron-stained gouge. On the left hand side of the tunnel, along which a sample was taken,

all of the ore is brecciated. On the right hand side, near the portal for about 25 feet, hard bunches of pyrite and pyrrhotite are exposed. The ore itself is fine-grained, usually running high in iron and carrying considerable sulfides. These have been largely leached out of the surface ore but show up in the clusters or bunches in the prospect tunnel and in the two open-cuts where the ore has been blasted out below the zone of oxidation. Samples were taken along the full length of the tunnel, as well as from those pits whose showings of magnetite warranted investigation. These samples assayed as follows:

	Fe	P	S	SiO ₂	Mn	TiO ₂
Open-cut below mouth of tunnel.	62.6	....	1.21	7.4	....	....
Open-pit 60' above tunnel mouth.	68.2	....	0.77	2.6	....	....
Prospect pit No. 12.....	54.6	....	0.24	23.6	....	....
Stripping 10'x25'	64.8	Tr.	Tr.	5.8	1.30	0.03
Along strike stripping 5'x20'....	47.2	....	0.10	13.6	....	....
Pit 40' SE of above stripping....	67.0	....	0.15	6.4	....	....
Small pit in center of orebody...	60.4	....	0.30	7.0	....	....
Small stripping 50' SE above sam.	52.6	....	0.30	12.0	....	....
Small strip'g nr. SE edge orebody	52.6	....	Tr.	15.2	....	....
Left side tunnel, 47'.....	49.6	0.05	0.54	11.7	0.37	0.10
Stripping 20' SE. above pit.....	65.4	....	Tr.	5.0	....	....

The first sample was taken from the open-cut just below the portal of the tunnel, where the ore has been exposed for about 10 feet below the surface and is less altered than that in the pits. This sample carries the highest percentage of sulfur. The second sample was taken from the largest open-cut, immediately above the tunnel, where the ore is exposed at a depth of 10 feet and this also shows high sulfur. The sample taken from the tunnel is rather low in iron and carries 0.54 per cent sulfur. This, however, is perhaps not a fair sample of the ore at the depth attained by the tunnel—from zero at the portal to about 25 feet at the face—since the tunnel has been run along a slip where the ore has been brecciated and disintegrated through the decay and leaching out of pyrite. It is probable that the ores run considerably higher in both iron and sulfur at this depth away from the tunnel.

Extent of Ore Deposit

The surface extent of the orebody can be estimated, but more development work in the form of shaft sinking or drilling is necessary before the depth can be known. Therefore no estimate of tonnage can be made at present with much degree of

accuracy. The surface pits indicate an outcrop roughly crescentic in outline with an average length of about four hundred feet and an average width of perhaps 125 feet to 150 feet. The difference in elevation between the lowest and highest points on the outcrop is 220 feet. Considering everything above the lowest outcrop as solid ore, the above dimensions give an estimate of about 1,610,000 tons. It is possible that the area underlaid by ore is greater than that indicated by the pits in which the ore is exposed. However, a number of pits in which bed rock was not exposed were deepened by Mr. Wilson and the writer and the bed rock was usually found to consist of garnet-epidote or badly altered intrusive rock with little ore in evidence. Considering the limited amount of development work, no accurate estimate of tonnage can be made and apparently no figure greater than the above is justifiable.

Mining and Transportation

Plenty of timber and water power is available at a low cost. The method of mining employed would be open-pit at first, followed by a combination of open-pit and milling as operations advanced. Consequently mining costs would be low. A great deal of gangue is scattered through the orebody in the form of masses of porphyrite and garnet-epidote rock which will have to be mined with the ore and will necessitate sorting.

The construction of about 2 miles of aerial tram will be necessary to transport the ore to tidewater. Also a wharf, at least one mile long, with bunkers will have to be constructed in order that vessels of desirable draft may land. A shorter wharf might suffice for barges but would not allow tugs to land except at high tide and would not be satisfactory for the landing of supplies.

Conclusions

Indications are that sulfides have been leached out of the surface ore and that sulfur increases with depth. It is evident that much of the ore will require some preliminary treatment, perhaps either roasting or magnetic separation, or both, before it can be successfully smelted.

Notwithstanding the fact that the orebody is almost entirely undeveloped at any depth, the surface work done so far indicates that, outside of the Texada island deposits, this is perhaps one of the two or three largest deposits of magnetite in the Pacific Northwest.

BRITISH COLUMBIA MAINLAND DEPOSITS

Hematite on Klinaklini River

A deposit of hematite assaying 47 to 57 per cent iron, with practically no phosphorus or sulfur occurs at an elevation of 9,500 feet, on the headwaters of the Klinaklini river, which empties into Knight inlet. The deposits are said to be very inaccessible and no considerable quantity of ore has as yet been proved. Consequently they have no commercial importance at the present time. A description of the deposits may be found in Brewer's report.

Limonite Ore Deposits in the Omineca Mining Division

Extensive deposits of bog iron ore occur on Summit creek, which is a tributary of the Zymoetz river, which empties into the Skeena river at Copper City, British Columbia. The main deposit is covered by nine mineral claims. They are located about 38 miles by trail from Copper City, the nearest station on the Grand Trunk Pacific railroad. Copper City is 40 miles from Kitmat, the nearest salt water harbor. This property was examined by Brewer in 1914 and also by MacKenzie, whose report appears in the Summary Report for 1915 of the Geological Survey Branch, Department of Mines, Canada.

The main orebody is said to consist of a bedded deposit of limonite which covers the bed rock on the north side of Summit (Limonite) creek valley, the slope of the hill being about 30 degrees. The area, which is entirely underlain by ore, is said to comprise about 50 acres, the lowest point of which is at an elevation of 2,600 feet and the highest point at 3,500 feet.

Part of MacKenzie's report is as follows:

Everywhere in this area, yellow or brown earthy limonite may be uncovered merely by removing the moss from the surface; there is no overburden except the trees and moss growing on the limonite beneath, and this vegetation has been removed by burning in two places, leaving large areas of the ore exposed.

The deposit consists of bedded bog iron ore, occurring in platy layers from 1 to 3 inches thick, lying parallel to the hillside, which here has an average slope of nearly 30 degrees. In addition to the stripping of the ore by burning, prospecting has been done by trenching and sinking numerous pits. The greatest thickness of limonite anywhere exposed is 15 feet; in two or three places 10 feet is exposed, and several cuts show 3 to 4 feet. In no place has the bottom of the sheet of ore been reached, and as no systematic attempt has been made to determine the quantity of ore present it is difficult to form any estimate of the amount available.

The ore consists of yellow and brown earthy limonite, free from sandstone or other impurities, rather soft and of a loose consistency, so that it may readily be dug with a pick or cut with an axe. The ore extracted from the large open-cuts has disintegrated on weathering to a crumbly, in part pulverulent mass, ranging in size of from a grain of powder to

fragments an inch or two across. It is thoroughly saturated with water as it lies in the bed, but when dried might run about 20 cubic feet to the ton, at a guess.

If the surface area be taken at 2,250,000 square feet, this figure would give 112,500 tons per foot of depth. An average depth of 5 feet for the deposit is almost certain; 10 feet is probable, and perhaps the depth is greater. In other terms, 562,500 tons may be considered as almost certainly proved; twice that as probable, and perhaps the amount is considerably larger.

Nine analyses taken from different parts of the orebody analyzed independently by three different assayers show uniformity of the ore in composition, the results indicating an iron content of 50.6 to 56.01 per cent; silica 0.83 to 2.0 per cent; manganese 0.39 to 0.85 per cent; phosphorus, 0.000 to 0.616 per cent; sulfur 0.8 to 2.65 per cent, and combined water 16.02 to 20.47 per cent. The analyses show the ore to be within the bessemer limit in phosphorus, but it is very high in sulfur. However, it is almost certain that in this kind of ore the sulfur is present largely in the form of sulfates which are not nearly as detrimental in blast furnaces smelting as sulfides.

The report of MacKenzie describes the country rock as follows:

The country rock on which the ore lies is an altered, greenish porphyry, containing in many places impregnations of pyrite. Across the valley of Limonite creek to the south this porphyry is in contact with quartz diorites of the Coast Range rocks, which are probably intrusive into it. The writer is informed that on the mountain side above and to the north of the iron deposit are many quartz veins carrying pyrite.

MacKenzie believes that the iron has been leached out of the sulfides in the country rock farther up the hill and transported to its present position in the form of sulfates by the surface waters from which it has been precipitated as hydrous iron oxide through contact with organic material. This process of ore deposition is said to be still going on at a comparatively rapid rate. Other deposits are reported to exist above and beyond this property.

Conditions are said to be ideal for cheap mining. It is stated that surface stripping would not be expensive and that mining would be carried on entirely by open pit or steam shovel operations. Plenty of timber and water power for all mining operations are reported to be available.

It is quite evident that a large body of ore exists here which, because of its physical nature, would be very desirable to mix with some of the hard, dense magnetite ores of the Northwest.

Kitimat Iron Deposit, near Grand Trunk Pacific Railroad

An extensive deposit of magnetite is reported to exist in the Kitimat valley, Skeena district. A description of the occurrences, by

William Manson, appears in the Minister of Mines' Report for 1908, as follows:

Iron Mountain camp is situated in the Kitimat valley, about 12 miles from salt water, on the southeastern end of Iron mountain. The ore is magnetite, with iron pyrites scattered through it in places. Where work has been done, gold, silver and copper values have been obtained. The southern extremity of the outcrop is on a level with the valley; from there the showing runs over the eastern slope of the mountain and down again to the valley, the distance between the ends of the outcrop being 3,200 yards, or nearly 2 miles. Its general direction is about 10 degrees east of north, while its dip is about 75 degrees west; the highest point on the outcrop is 900 feet above the lowest. The mineralized ground covers a width of 300 feet in places, consisting of solid bodies of magnetite, garnetite, and a greenish rock, the two latter having small quantities of magnetite scattered through them.

Cassiar District

J. A. Fraser, Gold Commissioner of the Cassiar district, reports in the Minister of Mines' Report for 1902 that an immense vein of magnetite iron ore carrying over 50 per cent iron has been discovered on Rant mountain, about 2 miles from Wells. Wells is at the mouth of the Chilkat river, which empties into the head of the west arm of Lynn canal, about 25 miles on an air line due west from Skagway.

Redonda Iron Mine

In the Report of the Minister of Mines for 1901 H. Carmichael reports a deposit of iron ore which occurs on West Redonda island, in Pryce channel, which is situated in Seymour Narrows, between Campbell river, on Vancouver island, and the mainland. It is said that the ore occurs at a contact between limestone and a light gray granite between well defined walls and that quarry operations have exposed a face of solid magnetite 30 feet wide by about the same height. The report states that in 1893, 626 tons of ore were quarried out and shipped to the Oswego Iron & Steel Company's furnace in Oregon.

Carmichael says that he was unable to form any opinion as to the continuity of the deposit in depth on account of surface covering and he fails to mention anything about the quality of the ore.

Deposit of Chrome Iron Ore in Lillooet District

Located on the north bank of Scottie creek about 3 miles above its mouth, where it flows into Bonaparte river, about 18 miles above Ashcroft and some 200 miles northeast of Vancouver, is a deposit of chrome iron ore. According to Brewer, who examined this deposit in 1915 for the provincial government of British Columbia, the country rock con-

sists of altered peridotite, which makes up most of the ridges and knolls, and carries a large percentage of chrysolite, and decomposed magnesium rocks, greasy and very highly colored with tints of green, yellow, and brown. Brewer says:

The erosion has been so extensive as to cut a series of deep gulches through the hills, leaving many of the knolls isolated from the main range of hills and with sharp peaks and precipitous sides. This erosion has laid bare the iron ore on the sides of some of the knolls and the points remaining between the gulches, so that the outcroppings can be followed from point to point in an easterly direction for a considerable distance. Sometimes the outcroppings occur as solid masses or beds of ore; at other places as nodules of varying sizes, some quite large, mixed with the decomposed rock.

The most important of these outcroppings shown on a point between two gulches, and a crosscut trench 20 feet long and about 6 feet deep has been made across a bed of fairly solid ore about 3 feet thick, dipping to the north; but sufficient work has not been done to permit of any estimate being made as to the extent of the deposit.

According to the report of the Minister of Mines for 1901, the year in which this deposit was discovered and located, three samples assayed, respectively, 47.11 per cent of chromium sesquioxide; 39.94 per cent and 31.26 per cent. The second sample was taken about 500 feet from the first and the third about 1,200 feet from the second.

Apparently this deposit is quite extensive, although it has not been developed sufficiently to make an estimate of tonnage possible. The ore is low grade, but it is possible that it could be mined and concentrated into a good shipping product. In case a steel industry is established on the Pacific coast chrome iron ore will be in demand up to a certain limited extent.

Hematite Deposits in the Goat River Mining Division

According to all reports available, there are large deposits of hematite, evidently of sedimentary origin, occurring near the town of Kitchener, British Columbia, in the Goat River mining division of the Nelson district. The deposits are said to consist of several parallel bedded veins 5 to 18 feet in thickness, which occur in a quartzite alongside a greenstone dike, and are supposed to be very extensive. The ore is reported to be a very good quality of hematite running high in iron and low in impurities. Descriptions of these ore deposits can be found in the Reports of the Minister of Mines for 1901 (pp. 1033-34), 1902 (p. 163), and 1903 (p. 149).

Although these deposits are apparently quite extensive and consist of a very good quality of ore, they are situated too far away from tidewater—some 500 miles or more by rail—to be considered of much importance at the present time.

Hematite in Nicola Mining Division, Yale District

According to the Report of the Minister of Mines for 1913 (p. 220), a body of hematite of unknown extent exists about 2 miles south-east from the town of Nicola, which is situated on the Nicola river in the Yale district, about 40 miles from the Canadian Pacific railroad, and over 150 miles from Vancouver.

In the Minister of Mines' Report for 1915 (p. 230), W. M. Brewer reports a body of iron ore about 3 miles from Nicola in an easterly direction. It is possible that this is the same deposit referred to in the report of two years earlier. If so, it is evident that the so-called hematite turned out to be bog iron. Brewer states that the orebody has been proved by open-cuts and ditches to have a lateral extent of 2,000 feet in length by 20 to 200 feet in width. The ore is apparently low grade, as is shown by the following assays:

Iron	22.0	52.0
Phosphorus	0.0	0.0
Silica	51.5	3.7
Sulfur	0.27	0.60

These deposits, like the hematite near Kitchener, are too far away from salt water to be considered of much commercial importance at the present time.

Miscellaneous Deposits

The Minister of Mines' report for 1915 (p. 293) states:

Other claims are being worked on Jarvis inlet by James Raper, the cuts and tunnels being in magnetic iron ore, carrying a small amount of copper.

Small showings of hematite on the Pend d'Oreille river, Nelson district, are described in the same report on page 167. Brown iron ore—probably limonite—occurs as bedded deposits near Chilliwack lake, Victoria mining division. The ore is said to occur in parallel bands alternating with bands of ocherous material and is fairly strong in appearance. A description may be found on page 304 of the above-mentioned report.

Surface showings of magnetite which are said to be of a highly encouraging nature are reported in the Minister of Mines' report to exist on Porcher island, Pitt island, and also on the mainland in the Skeena district. These deposits probably did not prove to be of much importance since the Gold Commissioner of that district failed to mention them in information which he furnished the writer on iron ore of that section.

Iedway Deposit—While on a trip examining the iron property on Louise island during the summer of 1916 the writer was informed by Mr. Ikeda, owner and operator of a copper property on Ikeda bay, Iedway channel, that magnetic iron ore not far from his copper deposit is owned by him. Iedway is the next channel south of Camshewa inlet, Queen Charlotte islands. Magnetite deposits which are very probably on this same property are described by R. G. McConnell in Sessional Paper No. 26, Summary Report of the Geological Survey Branch, Department of Mines, Canada, for 1909. This report is quoted as follows:

This claim is situated about a mile from Harriett harbor, Iedway, on the divide between it and Houston inlet, at an elevation of about 1,300 feet above sea level. It contains a large magnetite body about 400 feet in length with a width at one point of fully 100 feet. The magnetite is enclosed in porphyrite, except at the north end, where some crystalline limestone is exposed. It is unusually free from impurities, on the surface at least, but contains some garnet, epidote, calcite and cores of more or less altered country rock. Iron and copper sulfides in small quantities and some blende are also irregularly distributed through portions of the mass. The magnetite is reported to assay from \$2.00 to \$3.00 gold. It has remarkable magnetic qualities and acts as a natural lodestone. The development work consists of some stripping, a surface crosscut to determine the width of the orebody, and a short tunnel along the footwall.

Numerous other magnetite lenses up to 10 to 15 feet in width by 40 to 60 feet in length are reported in this vicinity but the above is the most promising.

TONNAGE ESTIMATES OF BRITISH COLUMBIA IRON ORES

By far the greatest amount of iron ore in British Columbia occurs in the form of magnetite replacements of country rock, which have been formed under the influence of igneous intrusions. The deposits are therefore very irregular in shape. For this reason and because of the nature of the deposit accurate estimates of tonnage are impossible without a great deal of development work which completely outlines the limits of the orebody, and makes estimates possible. There is not a single instance in which development work has been carried on to this extent. As a matter of fact, only a very few deposits have had an appreciable amount of work done on them. Considering these facts, it is evident that any estimate of the total tonnage of ore in the known deposits of British Columbia is scarcely more than a guess.

W. M. Brewer has made tonnage calculations of these deposits on Vancouver and Texada island which are in such a condition as to permit estimates being made. He has classified and tabulated his estimates under the headings "actual ore," "probable ore," and "possible ore." These he defines as follows:

(1) Actual ore, meaning thereby such quantity as development has exposed sufficiently to be considered as measurable and immediately available.

(2) Probable ore, meaning such ore as is only partially developed, not sufficiently so to admit of definite measurement, but of the occurrence of which the indications are sufficiently strong to warrant an assumption that such ore probably occurs.

(3) Possible ore, meaning such ore as is undeveloped, but which may possibly and is hoped to be found by further prospecting and development, the only indications of which are surface outcrops, and which may be postulated as possible from a knowledge of conditions.

Following is the table which he has compiled:

Name of Property —	Actual Ore-Tons	Probable Ore-Tons	Possible Ore-Tons	Total Ore-Tons
Ralph*	.....	.....	.....	.....
Rose*	.....	.....	.....	.....
Baden Powell and Little Bobs	.....	500,000	250,000	750,000
Sirdar	94,000	.....	47,000	141,000
Conqueror	16,000	230,000	120,000	366,000
Sarita (Prov. Min. estimate)	.....	30,000	25,000	55,000
Henderson Lake	20,000	.....	280,000	300,000
Black Prince	15,000	.....	15,000	30,000
Crown Prince	75,000	.....	200,000	275,000
Glengary and Stormont (Nootka Sound)	250,000	250,000	750,000	1,250,000
Fido (Nootka Sound)	.....	50,000	200,000	250,000
Quinsam Lake Iron Syndicate	.....	.....	5,000,000	5,000,000
Prescott (McConnell's estimate)	.....	1,366,400	993,600	2,360,000
Paxton (McConnell's estimate)	.....	1,607,200	.....	1,607,200
Lake (McConnell's estimate)	.....	504,000	.....	504,000
Klaanch river*	.....	.....	.....	.....
Totals	470,000	4,537,600	7,880,600	12,888,200

*In such condition that no estimate can possibly be made of tonnage available.

The amount of ore in the Louise island deposit is estimated by A. S. R. Wilson at 1,610,000 tons. The writer's independent estimate was a little higher than this, but the discrepancy was not great. The more conservative figure is given here. This, according to Brewer's definitions, would be classified as possible ore.

The only other occurrences on which estimates of quantity are available are the limonite deposits on the Copper (Summit) creek, Omineca division. These deposits have been estimated by J. D. MacKenzie at 562,500 tons of actual ore, and 562,500 additional tons of probable ore.

The total available estimates of ore in British Columbia, therefore, place the tonnage at 1,032,500 tons of actual ore, 5,100,100 of probable ore and 7,880,600 tons of possible ore, making a total of 14,013,200 tons. Of this estimate 562,500 tons of actual ore and the same amount of probable ore is limonite or bog ore, the remainder being magnetite. These estimates perhaps do not cover over one-half of the known deposits in British Columbia and the possible ore in the largest of these has not been estimated. It may, therefore, be concluded that the total amount of iron ore in British Columbia is perhaps two or three times the above figure.

Chapter V

ALASKA IRON ORE DEPOSITS

The only occurrences of iron ore in any appreciable quantities in Alaska, known to the writer, are certain deposits of chrome ore near the town of Seldovia on Cook Inlet and those on the Kasaan peninsula, Prince of Wales island. The former are described by Adolph Knopf in Bulletin No. 442 of the United States Geological Survey, pages 168 and 169, and are not considered to be of any commercial importance at the present time, and very probably not for many years to come. They are therefore omitted from this report. The Kasaan peninsula deposits, however, are now being worked for copper and may be developed for the iron. Other deposits are said to exist, but they have not been available for investigation.

KASAAN PENINSULA IRON ORES

Location

Kasaan peninsula is a neck of land projecting out from the central portion of the eastern coast of Prince of Wales island. It is bounded on the east and south by Clarence Strait and on the west by Kasaan bay.

The iron deposits under consideration are included within the properties known as the Mt. Andrew, Stevenstown and Maimie mines, which are located at the highest part of the south central portion of the peninsula, midway between its eastern and western shores. The properties are reached either from Hadley, which is situated on the bay of Lyman Anchorage on the east coast of the island and about $11\frac{1}{2}$ miles from the Maimie mine, or from the wharf and bunkers of the Mt. Andrew mine, which is situated on the west coast of the island and about $\frac{3}{4}$ mile below the mine on an air line. Hadley is some twenty-eight miles northwest from Ketchikan, while the Mt. Andrew wharf and bunkers are a little farther.

Geology

The geology of the Kasaan peninsula has been very carefully worked out by Charles Will Wright, and forms most of the subject matter of Professional Paper No. 87 of the United States Geological Survey.

The time at the disposal of Wilson and the writer during the examination of these properties in August, 1916, was very short and was practically consumed in the process of sampling the ore deposits. The opportunities for geological observations and study were therefore very limited.

Description of the Occurrences

The deposits are typical metasomatic replacements of sedimentary and igneous rocks occurring at, or near, a contact between granodiorite and Devonian limestone. They are very irregular in outline and are now being worked for copper which occurs in the form of chalcopyrite, together with other sulfides surrounding the magnetic lenses and often disseminated through the iron ore.

The origin of these ores is quite important. Wright has very clearly and concisely explained a theory which seems to fit the conditions in the field very well, and a few paragraphs are quoted here because they apply also to the majority of the magnetite deposits on the Pacific Coast. Speaking of the importance of the genesis of these ores, Wright says: "The determination of the origin of an ore deposit is not only of scientific interest, but of economic importance, for on this determination the miner must base his conclusions as to the depth to which the workable ore may extend and as to whether the ore will become more or less valuable with increase of depth."

Part of Wright's description of the occurrence of this type of deposits is as follows:

At the time of their intrusion the igneous rock masses or dikes forced their way through the sedimentary rocks, to some extent folding and fracturing them. While they were cooling both the intruded and intrusive rocks shrunk somewhat, and the shrinkage caused cracks and fissures to form near the contacts. These fissures become channels for mineral bearing solutions, derived, presumably, from great depths, where the temperature was high. On ascending along the contacts, where the temperature was lower, these solutions deposited their mineral content and to some extent replaced the rocks along their course. The contact deposits therefore lie within the contact zone, between the intrusive and intruded rocks, and are believed to have been derived from the same magma that formed the adjacent igneous rocks.

This theory would tend to favor the probability of extension of the ore body to a considerable depth. There is one other consideration, however, which must be taken into account before drawing any conclusions, namely, the stage of erosion at which the Kasaan peninsula has arrived. The minerals are practically all primary, oxidation products being insignificant in quantity, and everywhere is evidence that the forces of erosion have removed great quantities of material from

above the present ore deposits since they were formed. This consideration tends to lessen the probably extent of the ore bodies in depth.

Mount Andrew Mine—The Mount Andrew Mine is located at the top of the divide between Clarence Strait and Kasaan bay at elevation of about 1,000 to 1,400 feet and is connected with the wharf and bunkers on Kasaan bay by an aerial tram 3,600 feet in length. As stated elsewhere in this report, this mine has been in the past and is at present being worked for copper. Mining operations started in 1905 and have continued intermittently ever since.

Development work here is quite extensive. The main upper tunnel is about 600 feet in length and several hundred feet of drifts and cross-cuts driven at angles to this adit undercut the orebodies at 50 to 110 feet below the surface. At different places raises have been put through to the surface and mining has been carried on principally by glory holes or the milling system. At an elevation of 300 feet below this tunnel another adit 1,600 feet long with 200 or 300 feet of drifts, has been driven and connected with the upper workings by a raise put up from the face. Besides these development tunnels and drifts, three tunnels, each 50 to 75 feet in length, have been driven into the side hill, one above another, at two or three hundred feet west of the long tunnel on what is known as the Good Luck claim. Also two short adits, one above the other, 200 or 300 feet east of the 1,600-foot tunnel on what is known as the Jim Reco claim, are being worked at present (1917). A few feet, perhaps eighty, below these tunnels on the Jim Reco claim another tunnel was started during the writer's visit in August, 1916, which has since opened up a very good body of copper ore.

The ore from all of the lower workings of the mine is pulled up to the upper loading terminal of the main tram over a cross tram 1,000 feet or more in length by a compressed air engine and is transported thence to the beach over the long tram by gravity. The steam power plant which furnishes the compressed air for engines and drills is erected at the lower terminals near the bunkers.

The principal magnetite deposits which occur in this mine, and are likely to be of any commercial importance as iron ore, consist of very irregular bodies roughly lenticular in shape and ranging in size up to fifty feet in length by thirty-five feet in width on the surface outcrop. Magnetite also occurs disseminated through the ore, which is now mined for copper and which surrounds the more or less pure lenses of iron ore. The principal lenses of iron ore have not been

developed by work other than surface stripping because they do not contain copper in workable quantities.

Stevenstown Mine—This mine is located at the top of the ridge about $1\frac{1}{2}$ mile east from the Mt. Andrew mine and is connected with the Maimie mine on the northeastern slope by a surface tram 700 feet long.

The mine is developed by a tunnel 550 feet in length which penetrates the top of the mountain and which is connected with the surface by drifts and raises. Mining was carried on by glory holes, or surface pits, the ore being trammed out through the main tunnel below and transported over the surface tram to the Maimie mine and thence to the smelter at Hadley via an aerial tram 5,500 feet in length.

The ore here is similar to that at the Mt. Andrew, except that more pyrite and marcasite and less chalcopyrite is in evidence. The lenses are flat and have apparently been nearly all worked out. However, two or three small lenses of good magnetite ores were noted. The mineral zone is included between a monzonite intrusive which forms the footwall and Devonian strata of limestone and greenstone tuff which form the hanging wall.

Maimie Mine—This mine is situated just below and northeast of the Stevenstown Mine, at an elevation of 700 feet. Mining operations on a commercial scale began here in 1904, and have continued intermittently ever since. Development work here is of a considerable greater magnitude than at either the Stevenstown or Mt. Andrew mines. Mining has been carried on almost entirely underground in drifts and large stopes without timber. Only two glory holes were noted.

The orebodies consist of magnetite, pyrite, chalcopyrite, hornblende lenses of all sizes up to 50 feet in average width by 275 feet in length. They are included in and are usually entirely surrounded by the typical contact rock described elsewhere in this report and lie between diorite and limestone. Two porphyry dikes, 20 and 30 feet in width, respectively, are included in the mineralized zone. Also one diabase dike 15 feet wide cuts the diorite a few feet from its contact with the garnet-epidote rock.

Tonnages

The ore deposits are of such type and the conditions surrounding them are such as to prevent any statement of tonnage. Surface stripings have proven the presence of large quantities of magnetite, but mining has been carried on solely for the purpose of extracting copper and the purer iron ore lenses have not been developed. Of the

total amount of reasonably pure magnetite available in this district, by far the largest part is included within the Mt. Andrew property. The Stevenstown Mine has been almost entirely exhausted, and the ore in the Maimie Mine is not important as an iron ore.

Description of the Ores

With the exception of a few comparatively pure magnetite lenses in the Mt. Andrew Mine, and two or three in the Stevenstown and Maimie orebodies, the ores are so contaminated with sulfides as to make them of no value as iron ores in their present state. Furthermore, in the case of the Maimie deposits, the sulfides are so finely disseminated through the ore that preliminary treatment will be impracticable because very fine grinding would be necessary in order to separate the impurities from the magnetite. Much of the Mt. Andrew ore is quite coarsely crystalline and carries such a high percentage of iron as to warrant the separation of magnetite from sulfides and gangue minerals on a commercial scale; especially in the light of the fact that this ore carries from one to six per cent of copper.

Following are the results of assay of the samples collected in the field:

Mount Andrew Mine

Sample	Fe	P	S	SiO ₂	Mn	TiO ₂	Cu
1	60.8	....	0.54	10.5	....	....	0.00
2	65.8	....	3.60	5.4	....	....	3.36
3	35.4	0.056	2.50	20.4	0.37	....	Tr.
4	29.1	0.028	High	26.6	2.24	Tr.	6.25
5	46.2	....	1.41	32.3	....	....	0.90
6	13.9	....	High	High	....	....	1.84

Sample No. 1 was taken along the major axis of the surface outcrop of a magnetite lens 40 feet in length about 300 feet south of open pit No. 4, which has been exposed by stripping. This lens is apparently quite pure.

Sample No. 2 was taken along the major and minor axis, 50 and 35 feet in length, respectively, of a stripped area just above open-cut No. 10. The assay, however, shows that it carries considerable copper.

Sample No. 3 is a mixture of three sacks of ore, one from each of the three mines, which were broken and mixed in transit, and has little significance.

Sample No. 4 was taken from glory hole No. 3 and represents the copper ore as shipped from this mine.

Sample No. 5 was taken from the face of the upper tunnel No. 1, on the Good Luck claim.

Sample No. 6 was taken from the Peacock dump and consists of pyrite and chalcopyrite finely disseminated in an epidote-magnetite-hornblende gangue. It is of no value as an ore of iron.

Stevenstown Mine

Sample	Fe	P	S	SiO ₂	Mn	TiO ₂	Cu
1	44.2	0.056	2.5	15.3	0.0	0.0	0.12
2	34.1	....	High	High	....	....	2.28
3	32.1	....	High	High	....	....	2.80

Sample No. 1 is from the most southerly glory hole.

Sample No. 2 is from the most westerly open-cut.

Sample No. 3 from glory hole between No. 1 and No. 2.

No. 2 and No. 3 are fair samples of the basic ore shipped from this mine.

Maimie Mine

Sample	Fe	P	S	SiO ₂	Mn	TiO ₂	Cu
1	0.4	....	Low	53.2	....	....	0.4
2	39.0	Tr.	2.9	22.4	0.0	....	1.0
3	40.0	....	3.28	27.0	....	....	0.56
4	62.6	....	0.75	9.3	0.19	0.05	0.0

Sample No. 1 is siliceous ore from No. 4 stope and is of no value as an iron ore.

Sample No. 2 and No. 3 were taken from the ore bins at the tram loading station and represent the shipping ore.

Sample No. 4 was taken from the most easterly open-cut of the Maimie mine and represents high grade magnetite, though somewhat contaminated with sulfur.

Conclusions

The Alaskan iron ores investigated are, generally speaking, very much contaminated with sulfides and gangue minerals and most of them will require preliminary treatment before they can be successfully utilized in an iron blast furnace. There are, however, a number of good sized lenses of quite pure magnetite, which may be used directly without any preparation.

On account of the nature of the deposits it is impossible to make any estimates of tonnage with any degree of accuracy. It is quite evident that the total amount of magnetite deposits carrying over 50% iron is large in comparison with most of the deposits of the Northwest. Also a considerable amount of relatively pure magnetite ore is contained in a number of lenses.

If an iron and steel industry is established in the Northwest, it is very probable that the purer magnetite lenses referred to above will be mined. Conditions for cheap mining and transportation are very good. Concentration plants will have to be designed to treat this grade of material to produce an ore of high iron content suitable for the production of pig iron rather than flux for copper furnaces.

Chapter VI

OREGON IRON ORE DEPOSITS

The only known iron ores in Oregon of any commercial importance occur in Curry County in the northwestern corner of the state, and near the Willamette river about seven miles south of Portland. The Curry County deposits are described in the October, 1916, number of the "Mineral Resources of Oregon," Oregon Bureau of Mines and Geology, pages 60-66. The only description of the second deposit available appears in "The Commerce and Industries of the Pacific Coast," pages 311, by John S. Hittell.

CURRY COUNTY DEPOSITS

Three types of iron ores occurring in Curry county are described in the above named publication. These are designated, "boulder deposits," "bedded deposits," and "impregnation deposits."

Boulder Deposits

The boulder deposits are said to contain boulders of very pure magnetite in considerable quantities, but grave doubts are expressed as to the possibilities of their being utilized as iron ores. Part of the report states:

Even if later developments show it to be comparatively plentiful, it is unbelievable that any considerable iron mining industry involving the use of this ore will ever be developed. It is possible, however, that if a practical means is ever discovered for locating the boulder copper deposits which do not outcrop, considerable magnetic iron ore will be mined as a by-product. Whether this can ever be shipped profitably will depend upon the presence of transportation facilities much superior to those now in existence.

Bedded Deposits

The bedded deposits are said to occur in a metamorphic formation known as the Colebrook schist, the principal outcrops being on Wake-Up-Riley ridge. It is stated that "they have the appearance of lenses in the schist which lie parallel to the foliation" and apparently extend over a considerable area according to the results of magnetic surveys. G. M. Butler and G. J. Mitchell state that they had learned from reputable authorities that a very large outcrop of iron ore occurs at a point about seven miles southwest of this locality. They further state that the country rock over the entire area is Colebrook

schist, without any igneous rocks in evidence. This precludes the possibility of an igneous origin, and they suggest that these ores might have been laid down contemporaneously with the inclosing metamorphosed sediments as bog ore or as glauconite, and later changed to their present magnetitic condition by the forces of dynamic-metamorphism which acted over the entire formation.

These bedded ores are evidently low grade manganiferous magnetites. The authors state:

Two of the best looking samples, when analyzed, proved to contain, respectively, 28.29 per cent and 23.47 per cent iron, 12.95 and 7.30 per cent manganese, and a trace of phosphorus, but no titanium, arsenic, sulfur, or copper.

The economic importance of the bedded deposits as stated by the authors follows:

It is unlikely that any of the lenses now developed by open-cuts could be mined profitably, even if transportation facilities were much more favorable than they are. It is not improbable, as already stated, that larger lenses than those already located exist, and they may some time prove valuable. A careful magnetic survey of the region is needed, and, if this should indicate the presence of any considerable amount of ore, the means of transporting it would doubtless be provided, as there is a good market in the Northwest for this material.

Impregnation Deposits

One deposit of this type is reported to occur at an elevation of 3050 feet on a ridge running easterly from Horse Sign butte toward Collier creek. The deposit is said to be magnetite occurring as an impregnation in Myrtle sandstone between two greenstone dikes, and the report states that surface pits "indicate that it may be as much as 50 to 100 feet wide, and that it runs for some distance down both sides of the ridge." There seems no doubt that a large body of ore could be developed here. An average sample is reported to contain 51.45% iron, with no phosphorus, sulfur, titanium, arsenic or copper.

The conclusion of the authors of the report as to the economic importance of this deposit follows:

Although the iron ore as mined would be of rather low grade, it could be readily concentrated magnetically so as to materially increase its purity. As there is almost unlimited water power at no great distance, this would not be an expensive operation. The absence of detrimental elements, the apparently large size of the ore body, and the comparative ease with which it could be mined, combine to make this deposit well worthy of a careful investigation, and of exploitation, if transportation difficulties can be overcome.

BROWN HEMATITE ORE NEAR PORTLAND

A deposit of brown hematite iron ore occurs at Oswego, Oregon, on the Willamette river about seven miles south of Portland. This de-

posit was mined for a number of years, beginning in 1867, and the ore was smelted in the plant of the Oswego Iron Company.

The only available report on the property in question appears in "Commerce and Industries of the Pacific Coast" (1882), by John S. Hittell, page 311, and that part which relates to the deposit is quoted here in full:

The works are located on the west bank of the Willamette River, and are connected by railroad with the mine, which is three miles distant. The ore is conveyed by a tram of six cars, each one carrying a load of five tons, and is delivered by contract at seventy cents a ton. The average yield is about 100 tons a day, and at this rate it is estimated that will take fifty years to exhaust the deposit. The thickness of the vein varies from six to twenty feet, and a shaft has been sunk to a depth of 600 feet. The ore is a brown hematite, and yields about 40 per cent of iron.

The report states that about three tons of iron are required to produce one ton of pig iron. According to the figures given in this report, the deposit was estimated at that time (1882) to contain 1,825,000 tons of ore. The reports of the Mineral Resources of the United States show that 69,240 tons of pig iron have been produced at Oswego since the date of the above publication. At the rate of three tons of ore per ton of pig iron, this would indicate a depletion of the above estimate of 205,820 tons, leaving about 1,620,000 tons yet to be mined. The ore is apparently of low grade, but possesses good physical qualities.

OTHER IRON ORES NEAR PORTLAND

In 1904, a remarkable occurrence of so-called "iron ore" was reported near Portland, Oregon, by W. A. Roberts, of that city. This deposit was examined by J. S. Diller in company with Roberts. Diller's report on pages 343-347 of Bulletin No. 260, of the United States Geological Survey, shows the occurrence to have no commercial importance. In this same article Diller recalls the statement of S. F. Emmons to the effect that he (Emmons), while engaged on the Fortieth Parallel Survey, had discovered a large body of high grade iron ore near Palisade Canyon. An analysis of this ore by B. E. Brewster showed it to be of excellent quality. This deposit is probably not very important, however, since it is not mentioned in any other reports.

TONNAGE

No estimate of tonnage of iron ore in Oregon is available except the one above on the Oswego deposit; namely, 1,620,000 tons. There is probably more than this amount in the deposits in Curry County.

CONCLUSIONS

The only one of the Curry county deposits to be considered of any commercial importance is the magnetite deposit near Horse Sign butte, and this deposit is of no present value because of lack of transportation facilities. The poor qualities of the other ores of this county make them of no value as a source of iron at present and perhaps not even in the future.

The deposit at Oswego is evidently of some commercial importance, although it is low grade. It would probably make a very good ore to mix with Washington or British Columbia magnetites, and thereby produce a material of greater value for smelting.

Chapter VII

CALIFORNIA IRON ORE DEPOSITS

Although this investigation primarily covers the iron ore deposits of the Northwest, it was felt desirable to include within its scope the resources of California, because such ores can be regarded as tributary to any iron and steel plant which might be located on the Pacific Coast. For this reason, the most important iron deposits in California are briefly described here. These include the deposits of the Eagle Mountain district, Riverside county; the ores of the Redding quadrangle in Shasta county; and the Cave Canyon deposits in San Bernardino county.

THE EAGLE MOUNTAIN DEPOSITS

The Eagle Mountain deposits are the largest commercial iron ore resources of the west, with the single exception of the Minaret deposits which are larger in size, but not of as great commercial importance. These deposits were studied by E. C. Harder and their description forms the subject matter for Bulletin No. 503, United States Geological Survey, 1912. The following description is taken from that bulletin.

These deposits are located in the Eagle Mountains in Riverside county about 50 miles north of Mecca, a station on the Southern Pacific Railway, about 140 miles east of Los Angeles. They are replacements of dolomite which occur as beds and lenses in a dolomite and quartzite series which comprises the rock formation of this district and which forms a zone about $6\frac{1}{2}$ miles in length and in places some 4,000 feet in width.

Harder states that the individual dolomite or iron ore lenses and beds range in width of outcrop from 5 feet to 1,000 feet; in thickness, from 1 foot to 400 feet; and in length from 15 feet to more than a mile. The ore deposits consist largely of hematite and subordinately of magnetite, occurring as replacements in limestone, by hydrothermal metamorphism. Harder holds the opinion that magnetite and pyrite were the original minerals which have been altered to hematite. The pyrite has been almost completely oxidized, forming mostly hematite and a comparatively small amount of limonite, while the magnetite is still in the process of alteration to hematite.

The series of interbedded lenses of quartzite, and crystalline dolomite which contain the iron ore deposits are underlain by a series of schistose arkosic sandstones, varying in thickness from 50 to 300 feet and overlain by an intrusive sill of quartz monzonite of great thickness in which there are areas of quartzite and conglomerate. These rocks, together with the ore deposits, are cut by aplite dikes, and dikes and sheets of syenite porphyry, diorites, andesite porphyry, etc.

The ores themselves are very high grade and free from injurious impurities. The average analyses of sixteen samples by R. N. Dickman and McKenzie show that they range from 62.5 to 67% iron, 0.028 to 0.038% phosphorus, 0.038 to 0.214% sulphur, 2 to 6.7% SiO_2 , 0.25 to 1.04% CaO , and 0.2 to 2.16% MgO , with practically no manganese and no copper or titanite oxide.

A "moderate estimate" by E. C. Harder places the amount of high grade ore available at 60,000,000 tons. No iron ore has been missed, and development work consists of about 100 pits, shafts and tunnels. The longest tunnel is 124 feet long and the deepest shaft 18 feet deep.

These deposits are now controlled by the Harriman interests. Owing to their great extent, excellent quality, and comparative accessibility, they will probably be the first ores to be utilized in California when a blast furnace plant is established in that state.

ORES OF THE REDDING QUADRANGLE

The Redding Quadrangle is situated in Shasta County, Northern California, and embraces the north end of the Sacramento valley. Redding is the principal town.

These ores are described in Folio No. 138, United States Geological Survey, by J. S. Diller, and also in Bulletin No. 213, of United States Geological Survey, by the same author. The following description is taken from these sources:

Iron ore, magnetite, occurs in the Redding quadrangle at many places on the contact between the McCloud limestone and the quartz-augite-diorite. Although not mined, it occurs at two points in quantities well worth noting. The first is 1 1-4 miles southeast of Baird, and the second on the northeast slope of Hirz Mountain near McCloud river. The ore in both cases is chiefly magnetite with abundant limonite on the surface. At the first locality the material was formerly (1901-2) quarried for flux at Bully Hill. The occasional presence of small bands of garnet and traces of other related minerals locally in the magnetite indicate that it is a contact phenomenon similar to that in the Black Diamond region. The orebody has been opened to a width of forty feet without exposing its limits. It appears to be nearly vertical and its occurrence on the north slope of the hill suggests an orebody of considerable size. According to J. B. Keating, general superintendent at Bully Hill, it contains about 70 per cent of iron, 1 or 2 per cent of insoluble material, and only a trace of sulphur.

On the northeastern slope of Hirz Mountain the iron ore has a somewhat wider distribution, but this may be due to the gentle dip to the east, parallel to the slope of the limestone. It has been prospected by a number of open cuts, and, as in the other case, is generally a constant deposit on the borders of the limestone and diorite, but in places appears to penetrate the diorite.

In both cases the bodies of magnetic iron ore are large, but follow contacts of great irregularity. Each contains an element of promise of other orebodies, for at the Black Diamond mine, on the same contact, the magnetite is associated with chalcopyrite and pyrrhotite.

These deposits are apparently quite extensive and the ores are high grade. They are more favorably located than those of the Eagle Mountain district, and may be considered of great importance.

CAVE CANYON IRON ORE DEPOSITS

These deposits are located in the Cave Canyon district in San Bernardino County and are described by C. K. Leith in Bulletin No. 285, United States Geological Survey, pages 194-200, who visited the district in 1904. Mr. Leith's description is as follows:

A visit was made to the Cave Canyon iron area, about one-fourth of a mile north of Scott station, on the San Pedro Railroad (Cave Canyon Mines). It lies on the south side of the hills, between a complex of acid and intermediate rocks and coarsely crystalline marble on the south, dipping southward at about 30°. The iron is mainly along the contact, but projects into the igneous complex below and into the marble above. Little patches of marble were noticed in what was taken to be iron ore. The exposure is much broken and covered by desert varnish, with the result that the surface distribution is not at once obvious. While the iron ore debris covers the slope in several places, the igneous rocks appear through it. The ore occurs in two belts, one along the trend of the other, but separated by an erosion valley. The western belt is about 2,000 feet long and the eastern 1,700 feet long. The width of outcrop reaches a maximum of 450 feet. Its average width for the western belt may be 300 feet and for the eastern belt 100 feet. The true thickness of the orebody, assuming that it follows approximately the contact of the limestone, is probably less than half the width of outcrop because of the southward dip of the formation and the fact that the erosion slope follows the dip. Four tunnels are reported on the property. Two were seen in ore, the longest one thirty feet in length. The ore is mainly red hematite and limonite, soft and broken, showing limestone bedding. In one of the western tunnels green iron silicates were observed in the ore. The ore was not sampled. Commercial analyses from two sources show a percentage of iron above 60 per cent and phosphorus within the bessemer limit.

These deposits are apparently quite extensive and of considerable commercial importance.

TONNAGE

C. C. Jones, in a paper entitled "The Pacific Coast Iron Situation," in Volume LIII. of the Transactions of the American Institute of Mining Engineers (1915), page 307, states that, in his estimation, "the Eckel estimate of from 300,000,000 to 700,000,000 tons can be safely applied to the Pacific States alone, excluding the tonnages of

Utah and the other Rocky Mountain States; and, from our present knowledge, most of it is in Southern California." He estimates 200,000,000 tons of available high grade iron ore and double that amount of probable ore in Southern California. A "moderate estimate" of the Eagle Mountain deposits by E. C. Harder places them at 60,000,000 tons. The Cave Canyon deposits are estimated at 20,000,000 tons. Jones states that the Vulcan deposit, 236 miles east of Los Angeles, contains 6,000,000 to 10,000,000 tons of soft hematite of bessemer grade, and that the Colorado Fuel & Iron Company owns a deposit of 12,000,000 tons near Silver Lake on the Tonopah & Tidewater Railway. The large deposits in San Bernardino county described above and other large deposits elsewhere in the state are not estimated. Jones further states:

The Eagle Mountain, Cave Canyon, and Providence Mountain deposits, represent an aggregate tonnage of 125,000,000 tons, and have the characteristics necessary to the best possible furnace mixture for economical smelting.

CONCLUSIONS

From the foregoing, it can be seen that California has great resources of iron ore of excellent quality. None of the deposits is close to tidewater, and the ore must be transported by rail. Their development and utilization are dependent, in a large measure, on the trend of events in other parts of the Pacific Coast.

Chapter VIII

ESTIMATE OF TONNAGE OF IRON ORE RESOURCES OF THE NORTHWEST

The only tonnage estimates which, to the writer's knowledge, have been made of iron ore resources of the Northwest, are those of British Columbia. W. M. Brewer has compiled a table of tonnage estimates of most of the magnetite deposits on Vancouver and Texada islands. These include an estimate of the Sarita River deposits by the Provincial Mineralogist and R. G. McConnell's estimates of the Texada island deposits. The totals given are 470,000 tons of "actual ore," 4,537,600 tons of "probable ore" and 7,880,600 additional tons of "possible ore," making a total of 12,888,200 tons. J. D. MacKenzie has estimated 562,500 tons of actual ore and 562,500 additional tons of probable ore in the limonite deposits on the Zyometz river. A. S. R. Wilson estimates 1,610,000 tons of "probable" ore on Louise island. These available estimates total up to 1,032,500 tons of "actual" ore, 6,710,100 tons of "probable" ore and 7,880,600 tons of "possible" ore or a grand total of 15,623,200 tons. Probably not more than one-half of the known deposits in British Columbia are represented in these estimates, and the "possible" ore in some of the largest deposits has not been estimated. It is fair to assume that the total iron ore reserves of British Columbia are two or three times as large as the above figures would indicate. C. W. Hayes, in *Mineral Resources for 1908*, pages 120 and 121, estimates the available iron ore in British Columbia at 30,000,000 tons. From all of these figures the writer arrives at the conclusion that there are, in round numbers, 10,000,000 tons of available ore and 40,000,000 tons of ore not immediately available in British Columbia. Ore not immediately available is understood to mean ore which has not been developed sufficiently to warrant statements of actual tonnage.

No estimates have been made of the iron ore resources of Washington. After studying the various reports, the writer estimates 10,000,000 to 50,000,000 tons of ore which must be classed as not immediately available. It is impossible to give any estimate of available ore within reasonable limits.

The only estimate on Oregon deposits is one of 1,610,000 tons for the Oswego deposit. This might be considered as available ore.

About the same amount will be considered as available ore in the Curry County deposits. In round figures we may assume for the state of Oregon a total available tonnage of 3,000,000 tons, and of ore not immediately available, 10,000,000 tons.

No estimate of tonnage for Alaska iron ore deposits has been made and at present it is impossible to state reasonable limits within which the tonnage would probably fall.

Summing up the above estimates, we obtain 13,000,000 tons of available ore and 60,000,000 to 110,000,000 tons of ore not immediately available in British Columbia, Washington, and Oregon. The total iron ore reserves of the Pacific Coast are undoubtedly several times this amount. In Mineral Resources for 1908, pages 120-121, C. W. Hayes estimates the available tonnage on the Pacific Slope, including British Columbia, at 98,950,000 tons. He estimates 23,905,000 tons of ore not immediately available. His estimate of available ore for the Rocky Mountain and Pacific States is about 126,000,000 tons. E. C. Eckel, in "Iron Ores," places the minimum tonnage of ores in the Western States at 300,000,000 tons and the maximum at 700,000,000 tons.

C. C. Jones, in the paper already referred to, states that the Eckel estimate of 300,000,000 to 700,000,000 tons can be safely applied to the Pacific States alone. He estimates 200,000,000 to 400,000,000 tons in Southern California and perhaps as much more in Lower California and Mexico, which he says, "will naturally find an outlet to the northward."

From these widely varying estimates it is impossible to even conservatively judge the tonnage of ore which can be made available for immediate use in the event of the establishment of a local blast furnace plant. An adequate supply, however, is assured for many years for a plant of moderate proportions.

Chapter IX

ANALYSES OF IRON ORES OF THE PACIFIC COAST

WASHINGTON

No.	Location	Fe	S	P	Al ₂ O ₃	Reference
1	Clealum	42.5	0.03	0.039	21.90	Smith and Willis
2	Clealum	51.92	0.04	0.011	7.684	S. Shedd
3	Clealum	57.12	0.00	0.00	4.80	S. Shedd
4	Clealum	46.24	Tr.	Tr..	25.95	S. Shedd
					SiO ₂	
5	Snoqualmie	67.13	....	0.00	3.60	S. Shedd
6	Snoqualmie	66.82	....	0.00	4.20	S. Shedd
7	Snoqualmie	62.45	0.21	0.00	5.78	S. Shedd
8	Snoqualmie	68.54	0.25	0.00	1.89	S. Shedd
					Mn ₃ O ₄	
9	Hamilton	43.89	....	0.109	12.30	S. Shedd
10	Hamilton	32.14	0.06	0.314	11.74	S. Shedd
11	Hamilton	36.72	....	Tr.	13.04	S. Shedd
12	Hamilton	31.08	Tr.	0.179	14.28	S. Shedd
13	Hamilton	33.88	0.16	1.060	7.31	S. Shedd
14	Hamilton	43.91	....	0.690	12.00	S. Shedd
15	Hamilton	43.72	....	0.437	8.08	S. Shedd
16	Hamilton	32.92	....	0.327	8.11	S. Shedd
17	Hamilton	29.11	....	0.196	13.11	S. Shedd
18	Hamilton	46.6	....	0.59	0.19	S. Shedd
19	Hamilton	42.43	0.25	0.64	....	S. Shedd
20	Colville and				SiO ₂	S. Shedd
	Valley	67.56	0.38	....	1.66	S. Shedd
21	Col. andVal.	68.10	0.25	....	1.12	S. Shedd
22	Col. andVal.	56.58	0.32	0.31	4.49	S. Shedd
23	Col. andVal.	50.48	0.32	0.30	14.90	S. Shedd
24	Col. andVal.	59.19	0.33	0.16	5.80	S. Shedd
25	Col. andVal.	58.53	0.21	0.22	3.54	S. Shedd
26	Col. andVal.	41.7	....	0.117	10.3	Whittier
27	Col. andVal.	51.5	....	0.116	10.8	Whittier
28	Belcher	63.21	0.08	0.072	0.64	S. Shedd
29	Hanford	55.4	....	....	12.6	Whittier

BRITISH COLUMBIA

1	Texada Is. 61.0	0.10	0.017	6.9	Whittier
2	Texada Is. 62.2	0.90	0.023	5.6	Whittier
3	Texada Is. 60.3	0.07	Nil	7.9	Whittier
4	Texada Is. 65.1	0.05	0.024	8.3	Whittier
5	Texada Is. 62.6	3.17	Tr.	8.8	Whittier
6	Texada Is. 64.0	Tr.	Tr.	6.4	Whittier
7	Texada Is. 63.2	Tr.	Nil	8.2	Whittier
8	Texada Is. 68.8	Nil	Nil	4.0	Whittier
9	Texada Is. 59.5	0.06	0.031	5.7	Whittier
10	Texada Is. 51.0	....	....	15.4	Whittier
11	Texada Is. 62.57	0.403	0.024	6.46	McConnell
12	Texada Is. 55.20	0.266	....	....	McConnell
13	Texada Is. 59.40	1.07	....	....	McConnell
14	Texada Is. 57.50	0.046	....	....	McConnell
15	Texada Is. 69.4	0.001	....	....	McConnell
16	Texada Is. 68.2	Tr.	....	....	McConnell
17	Texada Is. 64.30	0.303	....	....	McConnell
18	Texada Is. 63.27	0.347	0.006	4.37	McConnell
19	Texada Is. 64.48	1.866	0.002	4.47	McConnell
20	Texada Is. 59.57	0.137	0.025	8.33	McConnell
21	Texada Is. 66.00	Nil	Tr.	3.3	Brewer
22	P. Renfrew 60.85	2.55	0.048	7.30	Lindeman
23	P. Renfrew 58.30	2.75	0.013	8.80	Lindeman
24	P. Renfrew 56.57	2.75	0.121	8.52	Lindeman
25	P. Renfrew 59.7	3.08	Nil	6.16	Brewer
26	P. Renfrew 62.98	Tr.	Nil	4.28	Brewer
27	P. Renfrew 67.09	1.60	0.009	4.51	Lindeman
28	P. Renfrew 69.2	0.50	....	2.7	Carmichael
29	Barclay Sd. 56.6	0.72	Nil	19.0	Brewer
30	Barclay Sd. 54.4	1.4	Nil	21.2	Brewer
31	Barclay Sd. 55.6	0.4	Tr.	17.6	Brewer
32	Barclay Sd. 48.4	0.7	Tr.	....	Carmichael
33	Barclay Sd. 48.06	0.623	0.006	23.22	Lindeman
34	Barclay Sd. 50.4	2.5	Tr.	10.6	Brewer
35	Barclay Sd. 60.7	Tr.	Tr.	13.6	Brewer
36	Barclay Sd. 63.8	0.55	Tr.	4.2	Brewer
37	Barclay Sd. 63.7	0.3	Tr.	3.85	Carmichael
38	Barclay Sd. 60.89	0.76	0.004	3.81	Lindeman
39	Barclay Sd. 56.2	1.3	Nil	17.0	Brewer

40	Barclay Sd.	50.4	0.3	0.053	18.6	Carmichael
41	Barclay Sd.	52.09	0.23	0.025	16.52	Lindeman
42	Barclay Sd.	55.7	0.3	.....	20.3	M. M. Report
43	Barclay Sd.	55.9	1.0	.....	16.0	Carmichael
44	Barclay Sd.	50.96	0.083	0.004	25.95	Brewer
45	Alberni				Cu	
	Canal	52.6	4.2	Nil	3.3	Brewer
					SiO ₂	
46	Alberni Cn.	66.0	Tr.	Nil	3.3	Brewer
47	Alberni Cn.	65.8	2.2	Tr.	4.8	Brewer
48	H'd'rson Lk.	50.0	0.24	Nil	22.0	Brewer
49	Hesquiat L.	50.0	....	.....	13.1	Carmichael
50	Hesquiat L.	59.8	0.55	.....	11.0	Carmichael
51	Nootka Sd.	56.8	0.1	Tr.	1.6	Brewer
52	Nootka Sd.	66.17	0.017	0.016	6.10	Lindeman
53	Klaanch R.	64.23	0.233	0.010	4.12	Lindeman
54	Klaanch R.	63.89	0.017	0.037	5.30	Lindeman
55	Quatsino S.	54.46	0.15	0.038	2.32	Lindeman
56	Quatsino S.	56.97	0.447	0.038	1.40	Lindeman
57	Louise Is.	62.6	1.21	.....	7.4	Whittier
58	Louise Is.	68.2	0.77	.....	2.6	Whittier
59	Louise Is.	54.6	0.24	.....	23.6	Whittier
60	Louise Is.	64.8	Tr.	Tr.	5.8	Whittier
61	Louise Is.	47.2	0.10	.....	13.6	Whittier
62	Louise Is.	67.0	0.15	.....	6.4	Whittier
63	Louise Is.	60.4	0.30	.....	7.0	Whittier
64	Louise Is.	52.6	0.30	.....	12.0	Whittier
65	Louise Is.	52.6	Tr.	.....	15.2	Whittier
66	Louise Is.	49.6	0.54	0.050	11.7	Whittier
67	Louise Is.	65.4	Tr.	.....	5.0	Whittier
68	Omineca D.	53.19	1.50	0.125	1.45	McKenzie

ALASKA

1	P. Wales	I.60.8	0.54	.....	10.5	Whittier
2	P. Wales	I.65.8	3.60	.....	5.4	Whittier
3	P. Wales	I.35.4	2.50	0.056	20.4	Whittier
4	P. Wales	I.29.1	High	0.028	26.6	Whittier
5	P. Wales	I.46.2	1.41	.....	32.3	Whittier
6	P. Wales	I.13.9	High	.....	High	Whittier
7	P. Wales	I.44.2	2.5	0.056	15.3	Whittier
8	P. Wales	I.34.1	High	.....	High	Whittier

9	P. Wales	I.32.1	High	.....	High	Whittier
10	P. Wales	I.39.0	2.9	Tr.	22.4	Whittier
11	P. Wales	I.40.0	3.28	.....	27.0	Whittier
12	P. Wales	I.62.6	0.75	.....	9.3	Whittier

OREGON

13	Curry Co.	28.29	Nil	Tr.	12.95	Ore. Bureau Mines
14	Curry Co.	23.47	Nil	Tr.	7.30	Ore. Bureau Mines
15	Curry Co.	51.45	Nil	Nil	.....	Ore. Bureau Mines

CALIFORNIA

16	Eagle Mt.	64.7	0.126	0.043	4.4	Dickman and MacKenzie
17	Redding	70.0	Tr.	.....	1 to 2	J. B. Keating

Chapter X

METALLURGICAL EXPERIMENTS

INTRODUCTION

The metallurgical work in the laboratory for this report consisted in assaying the samples collected in the field and concentration experiments on three classes of ores, namely, magnetite ore carrying a large percentage of gangue minerals from Texada island, pyritiferous copper-bearing magnetite ore from southeastern Alaska, and bog ore from northwestern Washington.

The results of the assays of the different samples collected in the field, although given under the descriptions of the various ore deposits which they represent, are here tabulated in condensed form for convenient reference. The results are as follows:

ASSAYS OF TEXADA ISLAND IRON ORES

Sample	Fe	P	S	SiO ₂	Mn	TiO ₂
1	62.2	0.023	1.24	5.6	0.39	0.00
2	61.0	0.017	0.10	6.9	0.30	Tr.
3	59.5	0.031	0.06	5.7	0.30	0.00
4	65.1	0.024	0.05	8.3	0.36	0.00
5	68.6	0.000	0.00	4.0	....	0.00
6	63.2	0.000	Tr.	8.2	....	....
7	64.0	Tr.	Tr.	6.4	....	0.00
8	62.6	Tr.	3.17	8.8	....	....
9	51.0	.....	1.20	15.4	....	....
10	60.3	0.000	0.07	7.9	....	0.00

ASSAY OF PRINCE OF WALES ISLAND, ALASKA, ORES

Samples from Mt. Andrew Mine

Sample	Fe	P	S	SiO ₂	Mn	TiO ₂
1	60.8	.....	0.54	10.5	....	....
2	65.8	.....	0.60	5.4	....	3.36
3	35.4	0.056	2.5	20.4	0.37	1.8
4	29.1	0.028	High	26.6	2.24	6.25
5	46.2	.....	1.41	32.3	....	0.90
6	13.9	.....	High	High	....	1.84

Samples from Stevenstown Mine

7	44.2	0.056	2.5	15.3	0.00	0.12
8	34.1	.....	High	High	....	2.28
9	32.1	.....	High	High	....	2.8

Samples from Maimie Mine

10	0.4	.....	Low	53.2	....	0.4
11	40.0	Tr.	2.9	22.4	0.00	1.0
12	40.0	.....	3.28	27.0	....	0.56
13	62.6	.....	0.75	9.3	0.19	....

ASSAY OF LOUISE ISLAND ORES

Sample	Fe	P	S	SiO ₂	Mn	TiO ₂
1	62.6	.....	1.21	7.4	....	....
2	68.2	.....	0.77	2.6	....	....
3	54.6	.....	0.24	23.6	....	....
4	64.8	Tr.	Tr.	5.8	1.30	0.03
5	47.2	.....	0.10	13.6	....	....
6	67.0	.....	0.15	6.4	....	....
7	60.4	.....	0.30	7.0	....	....
8	52.6	.....	0.30	12.0	....	....
9	52.6	.....	Tr.	15.2	....	....
10	49.6	0.050	0.54	11.7	0.37	0.10
11	65.4	.....	Tr.	5.0	....	....

Impure iron ores are prepared for blast-furnace smelting by the following methods of treatment:

1. Magnetic concentration.
2. Washing in log washers.
3. Crushing and sizing, followed by wet concentration on jigs and tables.
4. Dry separation.
5. Sintering, nodulizing, and briquetting.

Numbers 1, 3, and 5 are often combined. The method of treatment to be chosen depends entirely upon the ore to be concentrated. Magnetites are usually concentrated by magnetic separators. If the concentrates are fine they are usually sintered and nodulized in kilns and briquetted in briquetting machines. The non-magnetic tailings are often concentrated on tables. Brown clayey ores, and sandy hematites are washed in log washers, either with or without preliminary crushing. Soft ores, like those at Daiquiri, Cuba, are often nodulized and briquetted without preliminary crushing or washing.

ORE FROM TEXADA ISLAND, BRITISH COLUMBIA

A large sample of the material from the dump of the Prescott mine, Texada island, which had formerly been hand picked and discarded as waste during mining operations, was collected for experimental purposes. This represents fairly well that part of the Texada ore which will require treatment preliminary to smelting. The principal metallic minerals are magnetite, pyrite, marcasite, pyrrhotite and a small amount of chalcopyrite. The principal non-metallic minerals are garnet, epidote, calcite, quartz and actinolite.

The ore is usually very coarse grained and friable. The magnetite crystals, though small, occur in aggregates from $\frac{1}{2}$ to 3 millimeters in diameter which seldom include any gangue minerals. The problem of separating the gangue from the magnetite should therefore be comparatively simple.

It was found that by crushing to pass a ten-mesh screen, the magnetite was almost entirely freed from the adhering gangue minerals. The material, after crushing to ten mesh, was run over an Overstrom table without screening, with the idea of obtaining a good concentrate if possible, since the screening operation is expensive. The results were not satisfactory and so a classifier was interposed and numerous samples of the classified material were run over the table under different adjustments of table, feed, and water, but with little success. The heads and tailings from two of the best runs were assayed with the following results:

	Per cent iron		Per cent sulfur	
	Concentrates	Tailings	Concentrates	Tailings
Feed	51.0		1.20	
No. 1	52.3	47.9	0.90	1.70
No. 2	53.1	49.1	1.00	1.30

After a number of experiments with this material with no better results than the foregoing it was decided to screen size the feed before concentrating. The material passed through ten mesh and retained on twenty mesh was run over the Overstrom table and two of the best samples of products assayed as follows:

	Iron		Sulfur	
	Concentrates	Tailings	Concentrates	Tailings
1	59.0	31.3	0.37	3.10
2	60.2	32.2	0.25	3.00

The results of these last experiments gave very good concentrates, although a little high in sulfur, but too much iron was lost in the tail-

ings. However, a large part of the iron in the tailings was in the form of silicates, but the amount of Fe_3O_4 was not determined.

A sample of the material which passed through twenty mesh and was retained on thirty-five mesh was passed over the table with the following results:

	Iron		Sulfur	
	Concentrates	Tailings	Concentrates	Tailings
Feed.....	56.3		1.40	
	66.70	13.0	0.70	4.00

No magnetic separators being available, a sample of the product from a Dodge crusher was screened, sized, and separated with a hand magnet with the following results:

Mesh	Iron		Sulfur		%	Ext.	Remarks
Thru On	Con.	Tlgs.	Con.	Tlgs.			
.. 6	55.0	44.0	1.8	0.5	60		Sulfides not separated.
6 8	62.1	24.0	1.4	0.7	73		Sulfides not separated.
8 10	63.0	18.9	0.7	3.1	79		Sulfides still clinging.
10 14	65.7	7.0	0.6	3.6	82		Sulfides almost entirely freed.
14 20	65.4	8.0	0.3	5.6	81		Sulfides entirely freed.
20 28	65.5	8.0	0.3	17.5	..		Tailings largely pyrite.

The following analysis is from sample No. 1 of the Texada ores, which, with one exception, contains the highest percentage of sulfur of all of the samples collected on that property. It contained little gangue minerals, but was separated to eliminate the sulfides with the results shown.

Mesh	Iron		Sulfur		%	Ext.	Remarks
Thru On	Con.	Tlgs.	Con.	Tlgs.			
20 28	69.4	10.7	0.27	20.3	95		Tailings mostly pyrite.

These results were very satisfactory. Although it can hardly be expected that as good work could be done in actual practice with a magnetic separator, the ore would be an ideal one to concentrate by that means.

ALASKA ORES

Much of the Alaska ore is quite pyritiferous and also contains considerable copper for which it is being worked at present. The problem, therefore, from the standpoint of this investigation resolves itself into one of separating the gangue and sulfide minerals from the magnetite, thereby making a desirable iron concentrate and at the same time saving the copper. With this in view, a number of samples from the three different mines on the Kasaan peninsula were

mixed with the idea of obtaining as nearly as possible a representative sample of the ore which in that locality would require preliminary treatment. The analysis of this sample is represented by No. 3 of the Alaska ores in the above table of analyses. The principal metallic minerals are magnetite, pyrite, marcasite and amphibole.

The ore is generally very finely granular, the principal minerals being finely crystalline with the exception of calcite which has finely disseminated magnetite scattered through it. It is therefore necessary to resort to fine grinding in order to separate the magnetite crystals from the other minerals. Since fine grinding is necessary, it was decided to determine whether the sulfides could be floated by the flotation process and the magnetite recovered in the tailings in the form of a sufficiently concentrated product to make a desirable blast-furnace material after being briquetted. A sample was ground and a number of flotation experiments carried out under different conditions. The results, however, were entirely unsatisfactory, and it is only necessary to give the results of two of the most successful experiments here. They are as follows:

Iron		Copper		Insoluble	Sulfur
Concentrates	Tailings	Concentrates	Tailings	Tailings	Tailings
Feed . . . 35.4		1.8		20.4	2.5
23.7	38.4	8.30	0.18	21.2	0.5
31.9	42.2	2.62	0.27	22.0	0.8

The flotation concentrate, which from the standpoint of an iron ore would be the tailings, carries a large amount of iron, while the tailings are too low in iron and rather high in silica and sulfur to be valuable as iron ore. Moreover, when the conditions were such that the sulfides were practically all carried off in the froth, the tailings were small in quantity. Number one, however, gave a fairly good recovery of copper in the concentrate, and although about 92.5 per cent of the iron was recovered in the tailings these are poor in quality from the standpoint of an iron ore. However, the tailings might be magnetically concentrated and a desirable product obtained. With this in view a small sample of the tailings from No. 1 experiment was separated with a small horseshoe magnet with the following results:

Concentrates, 65.1 per cent iron; 0.10 per cent sulfur.

These results indicate that it might be possible to obtain a very good recovery of both iron and copper and produce very desirable products by a combination of flotation and magnetic separation. The copper would easily pay for the cost of flotation and agglomeration of

magnetite—in fact from the standpoint of profits, the iron would be the by-product instead of the copper. It was decided not to try any concentration tests on this ore with concentrating tables since no results were obtained from the Texada ore. However, concentrating tables, together with flotation machines and magnetic separators might figure in the flow sheet of a mill designed to treat this ore.

RESULTS ON MAGNETITE ORES BEING TREATED ELSEWHERE

The largest scale on which magnetite ores are treated is in the mills of the Witherbee, Sherman & Company at Mineville, New York. This company has a number of mills treating different ores. Mills No. 3, 4, and 5, employ dry magnetic separation and the magnetic separator is the only form of concentrator employed. The ores are coarsely crystalline and very similar to the Texada island ores. According to an article in Volume XLIV. of the Transactions of the American Institute of Mining Engineers (1912), by N. V. Hansell, the following results were the average obtained there at that time (1912):

	Iron	Phosphorus
Crude Ore	51.0	0.20
Concentrates	64.0	0.08
Tailings	10.0	

One and one-half tons of crude ore are required to produce one ton of concentrates.

In the same article it is stated that Ball & Norton double drum separators are used at Lyon Mountain, New York, where magnetite ore is crushed to 0.25 inch before separation, the middlings and tailings being recrushed and separated. The following results are the average obtained there:

	Iron	Phosphorus
Crude Ore	32.0	0.022
Concentrates	64.0	0.009
Tailings	9.0	0.034

Two and six-tenths tons of crude ore are required to produce one ton of concentrates.

Finely crystallized ores like those in Alaska are best treated by the wet process of magnetic separation. In this process the Gröndal separator is in widest use. The principal plants at which this process is employed are at Lebanon, Pa., and at Sellwood, Ont. In the article quoted above the following results are given for the Moose Mountain plant at Sellwood:

	Iron	Phosphorus
Crude Ore	36.19	0.072
Concentrates	65.58	0.020
Tailings	6.0	

Two tons of crude ore are required to produce one ton of concentrates. The concentrates are briquetted and sintered in briquetting kilns.

Results of wet magnetic separation with the Gröndal separator working on Cornwall ore at Lebanon, Pennsylvania, are as follows:

	Iron	Sulfur	Copper	Tons, based on 100 tons of feed
Feed	47.67	1.99	0.44	100
Concentrates	61.05	0.79	0.21	69.44
Nodulized Concentrates	61.05	0.08	0.21	69.44
Tailings ..	16.80	4.67	0.96	30.56

The tailings were run over Wilfley tables for the purpose of concentrating the copper with the following results:

	Iron	Sulfur	Copper	Tons, based on 100 tons of feed
Copper Concentrates ..	34.50	24.60	3.76	5.07
Copper Tailings	12.30	0.68	0.35	25.49

SUGGESTIONS AND CONCLUSIONS

The results obtained in the experiments on the Texada island ore indicate that it is very probable that this ore can be greatly improved by magnetic separation; in fact the results obtained elsewhere on similar ores on a commercial scale make this point almost certain. The dry method would be the most practicable one to use.

The results of the experiments on the Alaska ore indicate that this ore might be successfully treated by a combination of flotation and wet magnetic separation, although further experimentation with magnetic separators and flotation machines in different combinations will be required in order to fully demonstrate this point. Practice in other localities, using wet magnetic separators to remove the magnetite, and concentrating tables to save the copper values, might be successful.

Further experimentation will be necessary in order to properly design a mill for the treatment of the British Columbia and Alaska ores and to determine the costs of concentration.

Chapter XI

COKE, FLUXES, AND LABOR

COKE

Introduction

The question of coke for the blast furnace has been considered as one of the serious problems in the discussion of a possible steel plant on the Pacific Coast. Admitting that the ore and flux exist, many of the critics have claimed that no coking coal exists, that the coke which is at present made is of inferior quality, and is expensive. These points will be taken up and answered.

Coking Coals

Washington possesses ample reserves of coking coals. Practically all of the coal in Pierce County possesses coking qualities. Oregon is reported to have coking coals; and British Columbia has deposits of coal which are now being coked and used in copper blast-furnaces. Practically the entire supply of coke for metallurgical purposes in the Northwest comes from Washington.

Quality of Washington Coke

Pennsylvania produces the best coke in the United States and is considered the standard coke of the country. Following is a table showing the range of composition of Pennsylvania coke as given in Technical Paper 50 of the United States Bureau of Mines:

	Per cent
Moisture	0.23 to 0.91
Volatile matter.....	0.29 to 2.26
Fixed carbon	92.53 to 80.84
Ash	6.95 to 15.99
Sulfur	0.81 to 1.87

In the same paper is published an "Average Analysis of Washington Coke" as follows:

	Per cent
Moisture	0.92
Volatile matter.....	1.50
Fixed carbon	79.58
Ash	18.00
Sulfur	0.52

These analyses show that the Washington coke, although it does not come up to the Pennsylvania standard, is nevertheless of fairly good quality. It is a little low in fixed carbon and high in ash. This means that more coke will be required to produce a ton of pig iron, and a little more limestone will be required to flux the ash, but should not affect the quality of the iron. The Washington coke has one good feature, that of being low in sulfur and phosphorus.

The structure and physical properties of these cokes is good enough for all practical purposes, and the coke will stand up and maintain the burden in an iron blast-furnace. Tests made at the University of Washington by Joseph Daniels have demonstrated these points.

Quantity

The quantity of coke produced in the state of Washington during the last sixteen years has increased steadily from 35,921 tons in 1900 to 93,722 tons in 1916. The coal produced during this period has varied from 2,418,034 tons in 1900 to the maximum of 3,979,569 tons in 1910. Nearly all of the coke was produced from run-of-mine coal which was washed.

If a blast furnace of 500 tons per day capacity were established in the Northwest, it would require in the neighborhood of 180,000 tons of coke per year, or about twice the present production of the state of Washington. This means that the coke industry would be greatly expanded. The coal resources of the state, however, would insure an amply supply.

Cost

The actual cost of production of coke in the Northwest is probably higher than in the East, although it is difficult to get accurate data.

During the last year Connelsville coke has been quoted at \$7.50 to \$10.50 per ton, but this abnormal price has been due to war conditions and the consequent phenomenal advances in the prices of iron and steel products. In normal times the Connelsville quotations have been from \$1.75 to \$2.50 per ton.

Following is the average value of Washington coke per ton at the mine during the last seventeen years as published in the Biennial Report of the State Coal Mine Inspector for the period ending December 31, 1916:

1900	\$4.90	1903	5.00
1901	5.00	1904	5.00
1902	5.00	1905	4.75

1906	4.80	1911	5.81
1907	6.19	1912	5.54
1908	\$5.50	1913	5.62
1909	5.50	1914	5.15
1910	5.50	1915	5.32
	1916.....		\$5.20

These figures vary slightly from those of the reports of the United States Geological Survey, some being a little higher and some being a little lower, but the discrepancy is very small.

In estimating the cost of producing coke for the iron industry, it is necessary to bear in mind the fact that the increased production demanded will result in economies in mining and coking the coal. At present practically all of the metallurgical coke is made in bee-hive ovens. With the establishment of a steel plant, by-product ovens will be installed with a greater efficiency of operation, greater yield of coke and by-products, and a corresponding reduction in the cost per ton of coke. Any steel company owning its own coal mines would further reduce the cost of production of coke, and it is fair to assume that a ton of by-product coke may be produced under these conditions for \$3.50 to \$4.00 per ton, including all charges against coal and coke. At any rate, coke could be produced at tidewater for not over \$5.00 per ton. These figures are based on data collected at the University of Washington by Joseph Daniels. In order to be conservative, \$5.00 has been used as the price of coke in the calculations of cost of production of pig iron.

Conclusions

The fact that Washington coke is high in ash must be recognized. The ash content can be considerably lowered by more careful washing of the coal, but this will add a considerable expense to the cost of the coke. Ten to twelve per cent ash coke can be made if the industry demands it and will pay for it.

Experiments made on various coals indicate that mixtures can be used to produce metallurgical coke suitable for the iron blast-furnace in by-product ovens. This means that coals of various grades can be utilized, and widens the field of available coal resources. This coke will measure up to all the physical demands, just as the beehive coke which is now produced meets the physical requirements.

The cost of the coke will probably not be excessive in view of the conditions existing in the Northwest. The coke can undoubtedly be

produced for less than it would cost to import coke or ship coke from eastern or Rocky Mountain coal fields.

FLUXES

Large deposits of limestone of very good quality exist on Texada and Vancouver islands, British Columbia, and in Skagit and San Juan counties, Washington, in close proximity to tidewater. Limestone could be quarried out and delivered to any establishment located at tidewater in the Northwest at a very low cost. This limestone sells in the Seattle market for \$1.00 per ton, and it can be quarried for much less. For long-time contracts, or by mining direct, a steel company could probably get limestone for seventy-five cents per ton at its plant.

LABOR

At the present time on the Pacific coast there is a deficiency of labor skilled in the iron and steel industry. This is largely due to the fact that there is no large iron and steel industry on this coast and also to the fact that this industry is experiencing the greatest prosperity in its history in the east at the present time. However, if an iron and steel industry were established in the Northwest there is no doubt but that the necessary skilled labor would be attracted here. The climate and conditions under which the men work are healthful.

Unskilled labor is usually plentiful and of a higher type than is common in the eastern steel plants. Wages would be higher than in any of the eastern industrial centers, but not disproportionately so in view of the better type of worker. It is fair to believe that an ample and acceptable supply of labor exists in normal times and that a steel industry will have no difficulty in getting men.

Chapter XII

COSTS OF PRODUCTION

COST OF PRODUCTION OF PIG IRON IN THE BLAST FURNACE

The cost of production of pig iron on the Pacific Coast will be somewhat higher than it is in the East, but the difference is small in comparison with the cost of transporting eastern iron to this coast.

The principal items entering into the cost of producing a ton of pig iron are the costs of materials; transportation; general expense, which includes executives' salaries, stationery, office, engineering, special departments, watchmen, general maintenance, etc.; blowing; material used in repairs; power (steam); water; electricity; laboratory; tools and supplies; depreciation, etc.

The materials which need to be considered are the ore, coke, and limestone.

Cost of Ore at the Blast Furnace

The royalty or cost of the ore in the ground is estimated at \$0.50 per ton.

Mining will be largely by surface quarrying at the start, followed by glory-hole and underground mining later. Mining costs should, therefore, not be high. The average cost will probably be less than the average of underground mining of old range ores in the Lake Superior region, which is about \$1.50 per ton. This figure should, therefore, be a safe one to use. W. H. Lee says the cost of mining at the Texada island iron property has been about \$0.90 per ton in the past; \$1.50 will be used in these estimates.

Most of the iron ores of the Northwest are very handy to tidewater. Transportation will be by scows and the distance will not average over 200 miles. Fifty cents per ton on an average should cover the transportation charges.

The total cost of the ore laid down at the blast furnace is estimated at \$2.30-\$2.50 per ton.

Cost of Coke

As stated in the discussion under coke, the cost of this material may be taken to be \$5.00 per short ton laid down at tidewater.

The amount of coke required in the Pittsburg region is 1 to 1.1 tons per ton of pig iron produced. The amount required in the North-

west will be a little higher on account of the higher ash content. One and one-quarter tons of coke will, therefore, be taken as the quantity required to produce a ton of pig iron. The cost will be \$7.00 per long ton of pig iron produced. The cost will vary a little, depending upon conditions, but the figure given is considered a safe one to use.

Cost of Limestone

The cost of limestone will be that of quarrying, loading, and towing to the blast furnace. This should be very low and should not exceed a dollar per ton, which may be taken as a conservative estimate.

General Expense

The total general expense is small in comparison with the other items and may be taken to be the same as in Pittsburg or Chicago. It is almost impossible to obtain cost data first hand from plants in actual operation on account of the reluctance of companies to give out such information. However, Mr. Sidney Cornell, in an article entitled, "The Working Efficiency of Rolling Steel" in the *Metallurgical and Chemical Engineer*, for August 15, 1916, has tabulated quite completely the various items of cost in a large iron and steel plant located some twelve miles from Pittsburg. His estimate of general expense and other small items may be taken to apply to a plant located in the Northwest. They are as follows:

General expense, including salaries, stationery, office, engineering, special departments, watchmen, general maintenance, etc., 10c per ton; blowing, 15c per long ton of pig iron produced; material used in repairs, 10c; power (steam), 25c; water, 6c; electricity, 2c; laboratory, 2c; tools and supplies, 2c; and he estimates 18c for depreciation. This item would probably be a little higher in the Northwest on account of the fact that a plant here would be much smaller than the one which Mr. Cornell refers to and the capital outlay per ton would, therefore, be larger. Depreciation is, therefore, estimated at 25c per ton. The total general expense and other items amount to \$0.72 per ton of pig iron produced.

Labor Cost

According to reliable steel men, the labor cost should not exceed ten per cent of the cost of producing pig iron. On the basis of \$15.00 pig, this will be \$1.50 and this figure will, therefore, be used in this estimate.

Summary of the Cost of Producing One Long Ton of Pig Iron in the Northwest

Iron Ore, 2 tons@ \$2.50 per ton, per long ton pig iron.....	\$ 5.00
Coke, 1.25 tons@ \$5.00 short ton, per long ton pig iron.....	7.00
Limestone, 1,200 pounds@ \$1 long ton, per long ton pig iron..	.54
Maintenance	.25
General expense and small items.....	.72
Labor	1.50
Total cost	<u>\$15.00</u>

The quantities of materials used in this estimate are taken from a charge sheet figured out by the author in which the ore was assumed to contain fifty per cent iron, which is lower than the average Northwestern magnetites. On the basis of a 60 per cent iron ore, the cost of pig iron would be \$13.95 per ton. If the flue dust were recharged, the cost would be still lower.

These estimates are not very different from an estimate of the cost of producing pig iron in Los Angeles, by Charles Colcock Jones in Transactions of the American Institute of Mining Engineers, Volume LIII (1915), page 306. Mr. Jones' estimate for Los Angeles was \$13.74. Conditions, however, are a little different in Los Angeles. There coal is assumed to be imported from Sunnyside, Utah, and manufactured into coke and by-products at Los Angeles. Also the iron ore is assumed to be hauled 260 miles by rail. Transportation costs at a California plant will, therefore, be considerably higher than in Washington or British Columbia. On the other hand, the mining costs in the southern state will be considerably lower than in the Northwest because open-pit mining may be employed almost entirely in the former case. These factors just about balance each other.

Comparison of Costs With Those in Pittsburgh

As stated above, figures on the cost of production at plants in operation are very hard to obtain. However, William S. Bowron figured out "The Cost of a Ton of Pig Iron in the Sequacher Valley," which was published in Transactions of the American Institute of Mining Engineers for 1888-1889. His final estimate at that time was \$10.82 per long ton, which he stated was very near the average.

Oldersterna gives the average cost of making one ton of charcoal iron at the Hinkle Works, Ashland, Wisconsin, in 1896 as \$11.77.

In 1899 the cost of smelting in Pittsburgh was \$9 to \$11 per ton, while Kirchoff gives \$10.82 as the average cost for 1901.

W. B. Phillips gives several detailed accounts of the cost of producing pig iron in the United States in the *Engineering and Mining Journal*, for August 31, 1901.

Mr. C. C. Jones says:

In 1906, before the Ways and Means Committee of the House of Representatives, Judge Gary testified that for all the furnaces of the United States Steel Corporation, the total cost of making a ton of pig iron, based on the market prices of iron ores, coke, limestone, cinder, and scale, and including maintenance and depreciation of furnaces, was \$15.30 per ton of pig iron.

From this total cost \$3.71 is deducted for profits on ores, coke and transportation, leaving \$11.59 as the net cost. That was in 1906.

In Cornell's article of August 15, 1916, he estimates the prime cost of pig iron at the plant under consideration near Pittsburg at \$12.019 per ton. This figure is the one which should be used as the basis of comparison for conditions existing at the time these estimates were made. Costs at the present time, however, are so widely different on account of war conditions that it is not safe to generalize, and allowance must be made for the abnormal situation. The estimates, therefore, show a discrepancy of \$2.00 to \$3.00 per ton in favor of Pittsburg.

The railroad freight rates from Chicago or Pittsburg to Seattle on pig iron in carload lots at 80,000 pounds minimum weight per car are \$0.40 per 100 pounds, or \$8.00 per ton. This makes the cost of eastern pig iron laid down on Puget Sound \$6.00 per ton higher than the estimate of the cost of producing iron here.

E. J. Manion, of Dodwell & Co., shipping agents, says that water rates on iron and steel are now about \$15.00 per ton from eastern ports to Seattle via Panama Canal, and that they would probably average \$8.00 per ton in normal times. To this cost would have to be added the freight rate from Pittsburg to New York, which would make the cost greater than by rail.

The average selling price of pig iron on the Pacific Coast in normal times is \$21 to \$25 per ton. At present it is much higher, since it is quoted in Pittsburg at \$40 to \$48 per ton, but these are abnormal times on account of the war.

COST OF PRODUCTION OF PIG IRON IN THE ELECTRIC FURNACE

The only practicable way to get at any estimate of the cost of producing pig iron in the electric furnace in the Northwest is to compare the probable cost of the various items here with their cost in Sweden, where the industry is on a sound basis. Dr. Alfred Stans-

field spent the greater part of the summer of 1914 studying the industry in Sweden and his report, entitled "Electrothermic Smelting of Iron Ores in Sweden," has been published by the Canadian Department of Mines. Cost data of production in Sweden contained in that report will be used in the following estimates.

According to Stansfield, the items to be considered in the cost of producing electric furnace pig iron are the ore, lime, charcoal or coke, electrical energy, electrodes, labor and engineering, office and organization, repairs, depreciation, general expenses and petty charges. Of these the ore, power and charcoal are the largest items.

On account of stoppage for relining, holidays, etc., and the power utilized not being equal to the maximum, the total amount of power consumed amounts to about 82 to 83 per cent of the total power paid for. The total power used is about 2200 K. W. H. per ton of pig iron. The total amount paid for is, therefore, about 2700 K. W. H.

The following estimate may be taken as the average cost of producing one metric ton of pig iron in the Elektrometall furnace in Sweden from sixty per cent iron ore:

1700	Kilograms ore@\$.4 per ton.....	\$ 6.80
150	Kilograms limestone@\$1.35 per ton.....	.23
23.8	Hectoliters charcoal@\$0.18 per hectoliter.....	4.28
2700	Kilowatt hours@0.126c per kilowatt hour.....	3.89
	or 0.41 horse-power years @\$9.50 per horse-power year	
4.5	Kilograms electrodes@\$0.09 per kilogram.....	.40
	Labor and engineering	.90
	Office and organization	.50
	Repairs	.35
	Depreciation (6% of \$240,000 for yearly output)....	.51
	General expenses	.50
	Petty charges	.44
	Total cost	\$18.80

In estimating the cost of producing electric pig iron in the Northwest, the same figure of \$2.50 per ton which was used in the estimate of cost of ore for blast furnace production will be used here. The ore is assumed to contain 60% iron. Limestone will be considered to cost \$1.00 per ton, as above. Charcoal is at present manufactured and sold in Oregon at \$12 per ton. By manufacturing it on a large scale, which would be necessary in the iron industry, and utilizing the by-products, it should be possible to produce it for \$5.00 per ton. The gas should be utilized for generating power or, if the plant were located

near a city, it may be sold. This figure of \$5.00 per ton will, therefore, be used in this report. These figures, so far, are on the basis of a long ton, or 2,240 pounds. They will be taken to apply to a metric ton, or 2,204 pounds, which will give a little larger factor of safety.

The lowest price at which power is quoted in Seattle is 0.5 cent per kilowatt hour for 720 and over kilowatt hours per month. However, Professor Magnusson of the University of Washington says that the cost would be considerably lower for large quantities, perhaps 0.3 cent or under. The power cost delivered at the plant also depends upon the distance of transmission. For this reason, in addition to the fact that charcoal can be produced much more cheaply when it is possible to utilize the by-products, it would probably be found to be most practicable to locate the plant near a large city. For the purpose of this report the plant will be assumed to consist of three electric furnaces of 4,000 horse-power each. An estimate of 0.3 cent per kilowatt hour should be conservative for the power cost where such a large quantity is utilized. The cost would probably be considerably lower than this.

The cost and consumption of electrodes will be considered the same as in Sweden, or nine cents per kilogram.

Labor will be much higher here. In Sweden, the men are paid about twelve cents an hour on an average. A large part of the labor is skilled. The cost in the Northwest would probably be three or four times this amount. The cost of labor and engineering will, therefore, be estimated at four times the cost in Sweden, or \$3.60 per ton.

Stansfield has estimated the complete cost of an electric furnace plant in Canada consisting of three furnaces of 4,000 horse-power each at \$360,000. He estimates depreciation at six per cent of this amount on the yearly output, or \$0.72 per ton. This figure will be used here.

The other items of expense should not be materially different from those in Sweden and for the purpose of this report will be considered to be the same. We are now ready to compile an estimate of the cost of producing one metric ton of electric-furnace pig iron in the Northwest, assuming the plant to consist of three furnaces of 4,000 horse-power each and to be located at Seattle, with other conditions assumed as outlined above. The estimate is as follows:

1700	Kilograms ore (60% iron) @\$2.50 per ton.....	\$ 4.25
150	Kilograms limestone @\$1 per ton	.15
380	Kilograms charcoal @\$5 per ton.....	1.90

2700	Kilowatt hours@0.30c per kilowatt hour.....	8.10
4.5	Kilograms electrodes@\$.09 per kilogram.....	.40
	Labor and engineering	3.60
	Office and organization	.50
	Repairs	.35
	Depreciation (6% of \$360,000 for yearly output).....	.72
	General expense	.50
	Petty charges	.45
	Total cost	\$20.90

Stansfield estimates the cost of producing one ton of pig iron in Canada as follows:

(a)	Electric White (Charcoal) pig iron.....	\$20.00
(b)	Electric Gray (Charcoal) pig iron.....	21.00
(c)	Electric White (Coke) pig iron	18.50
(d)	Electric Gray (Coke) pig iron.....	19.50

His estimates on power and labor, however, are taken to be the same as in Sweden, which would hardly be justified here.

D. A. Lyon, in an article entitled "Electro-Metallurgical Industries as Possible Consumers of Electric Power," in Volume LII (1915) of Transactions of the American Institute of Mining Engineers, page 827, estimates the gross cost of producing pig iron in the electric furnace on the Pacific Coast at \$26.21. His estimate of net cost would be \$25.19, since he allows an interest charge of \$1.02. The principal discrepancies between the above estimates and Lyon's are in the costs of ore, fuel, power and labor. Lyon estimates \$5.00 per ton for ore, \$10 per ton for charcoal or coke and \$5.00 per ton of pig for the labor cost, which, in the writer's opinion, are rather high. His estimate of power cost, however, is lower, 0.18 cent per kilowatt hour, which may be nearer correct than the figure of 0.30 cent used by the writer.

CONCLUSION

Pig iron can be produced on the Pacific Coast for several dollars less than eastern iron can be delivered in the Coast cities. Pig iron manufactured by electrothermic smelting in the Northwest should be produced at a cost not much higher than in Sweden. The cost would be considerably higher than the cost of smelting in the blast furnace, but the superior quality of product in the former case would command much higher prices. As stated elsewhere, the electric furnace was never meant to compete directly with the blast furnace, but rather to cover a slightly different field.

Chapter XIII

MARKETS

The market is a very important factor in the success of any industry and in the case of the iron and steel industry, it is particularly vital. In discussing the Pacific Coast market as a factor in the establishment of a local steel plant, it is necessary to consider the competition from other centers. This would include a consideration of the costs of production in the different localities, together with the freight rates to the competitive markets. The freight differential or margin will govern the zone in which the products of eastern plants will meet the product of a local industry on an even footing. In addition to these competitive factors, it is necessary to consider the present and prospective consumption within the field, the present imports and exports and the outlook for future markets.

COMPETITION

In 1915, the total number of blast furnaces in the United States west of the Mississippi river consisted of six in Colorado, two in Missouri, and one in Oregon, of which only three were in operation, two in Colorado and one in Missouri. The fact, however, that nearly all of the pig iron used on the Pacific Coast at the present time is imported either from the East or from the Orient eliminates considering the Missouri and Colorado plants as competitors. Since freight rates on iron and steel from Chicago to the Pacific Coast are the same as those from Pittsburg and since the figures on cost of production in the East contained in this report are for the Pittsburg district, the latter will be the only domestic competitor considered.

The present rate on pig iron in carload lots of 80,000 pounds minimum from Chicago or Pittsburg to Seattle by rail is \$8.00 per ton. As stated under Costs of Production, this rate is probably lower than the rate from Pittsburg to Seattle via the Panama Canal would be in normal times. At the present time, the railroad freight rates to Great Falls, Butte and points west of those places are equal to or less than freight rates from Chicago or Pittsburg to those points. Railroad men promise that if an iron and steel industry is established on this coast regular commodity rates on iron and steel will be inaugurated and the line of equal rates from Pacific Coast points and from Chi-

cago and Pittsburg will be pushed still farther east than Montana. With this possibility in mind it seems reasonable to include Washington, Oregon, California, Idaho, Montana and Utah within the market field.

The Orient is also a young and growing market for high grade bessemer pig iron and steel. The Orient, however, exports more pig iron to the Pacific Coast than she imports. Very little pig iron, in fact, is exported from the United States via Pacific Coast States, the quantity running as low as four tons and never exceeding 398 tons in any one month during 1916. On the other hand, Pacific Coast states import about 1,000 tons per month. It is estimated that about 100,000 tons of pig iron is used per year in the state of Washington alone at the present time. The total consumption in Washington, Oregon, California, Idaho, Montana and Utah easily exceeds 20,000 tons per month. Since only about 1,000 tons per month is imported, over 90% of the pig iron consumed in this region must be produced in the eastern states and less than ten per cent is imported from the Orient. It seems, therefore, that the Orient is not a serious competitor. In fact, the Oriental competition is declared by prominent mining engineers to be a sort of a "bug bear" on the Pacific Coast and does not amount to much. The water rates from the Orient would also handicap Chinese pig iron. E. J. Monion of Dodwell & Co. informed the writer that the present rates to the Orient on iron and steel are up to \$20.00 per ton; that they have been as high as \$40.00 and as low as \$3.00, but would average in normal times perhaps \$5.00 per ton.

Pig iron of the same quality as Chinese or Japanese pig could be manufactured in the Northwest at \$5.00 per ton greater cost than in the Orient and still compete. There is also one other factor, namely that Oriental pig iron is of an inferior grade to that which could be produced on the Pacific Coast. Oriental competition is, therefore, not to be considered as a serious matter.

CONSUMPTION WITHIN THE MARKET FIELD

Figures were obtained from prominent Seattle foundry and steel men from which the writer was able to estimate a total present consumption of pig iron within the western market field of 250,000 to 300,000 tons per year.

C. C. Jones, in his article on "The Pacific Coast Iron Situation" in September, 1915, gives 100,000 tons as the estimated yearly consumption on the Pacific Coast at that time "according to one of the leading buyers of iron and steel." The consumption has evidently

more than doubled since that time. Jones gives estimate of consumption on the Pacific Coast in 1915 as follows:

	Tons
Pig Iron	100,000
Reinforcing Steel for Concrete Buildings.....	30,000
Sheets	136,000
Plates	217,000
Corrugated	15,000
Bar	175,000
Structural	250,000
Total	923,000

These figures are undoubtedly much larger at the present time, and particularly those covering sheets and plates, on account of the phenomenal growth of the shipbuilding industry which the Northwest is now experiencing.

Considering these facts, it is the writer's opinion that the market is even now ample to support an iron and steel plant consisting of a blast furnace of 450 to 500 tons per day capacity, together with the refining and rolling equipment necessary to manufacture the pig iron into the various merchant forms and shapes.

IMPORTS AND EXPORTS

The total imports of iron and steel to the Pacific Coast are inconsiderable. The total value of all iron and steel products imported to the four customs districts of the Pacific Coast during the month of August, 1915, was only \$41,142 and the total value for August, 1916, was only \$65,542.

The exports on the other hand amounted to a considerable sum. In August, 1916, \$2,356,592 was the total value of iron and steel products and manufactures thereof exported to other countries by way of the Pacific Coast. No figures are available for August, 1915, except for the Washington district, which amounted to \$975,898. A very small portion of these values represents pig iron. Nearly all of these exports went to Canada, Russia and the Orient. The largest proportion was undoubtedly manufactured in the East.

If an iron and steel plant were established on the Pacific Coast most of these iron and steel exports would be manufactured on this Coast instead of in the eastern states. This trade alone would be sufficient to support a medium sized industry without considering the local consumption.

OUTLOOK FOR FUTURE MARKETS

It is quite evident that the advent of the establishment of an iron and steel industry in the Pacific Northwest would be accompanied by great prosperity in the shipbuilding, steel casting, canning and allied industries in which large quantities of iron and steel products are used. These industries would increase by leaps and bounds just as the local shipbuilding industry is moving forward in spite of its great handicap in being unable to obtain steel plate.

In addition to the inevitable increase of domestic consumption of iron and steel the export market is also destined to become more important. It is evident from the figures on exports that this market even now is quite important. Furthermore, it is increasing at an enormous rate. In an article entitled "The North Pacific Coast, Newest Great American Center of Foreign Trade," by Teel Williams, published in the *Pacific Builder and Engineer* of March 30, 1917, the figures for exports to Siberia, Manchuria, Russian Poland and Russia proper bring out this point very clearly. Speaking of the record of exports from the Washington Customs District for 1916, Mr. Williams says:

There is, however, this much to base prophesies on: While war munitions made possible the record, it is yet a fact that approximately forty-eight per cent of the foreign trade through this district was made up of a wide diversity of American manufactured goods, which were not destined for war purposes.

The Russian and Oriental market, in the writer's opinion, is just beginning to develop and will continue to do so after the great war, which is a large factor in the present expansion of that field, and it may be safely assumed that the outlook for future markets in the Pacific Northwest is exceptionally bright.

CONCLUSION

The preceding analysis justifies the conclusion that a local steel industry will find a fair market in nearby territory and that it will bring with it a train of dependent establishments and will result in building up the local market as well as extending its limits to territory which is now served by eastern plants. The export trade would undoubtedly be controlled by the steel industry of the Pacific Coast.

Chapter XIV

GENERAL CONCLUSIONS

The general conclusions to be drawn from the investigation of the iron ore resources of the Northwest are as follows:

DISTRIBUTION AND EXTENT OF IRON ORE DEPOSITS

The iron ore resources of the Northwest consist of a large number of widely scattered deposits which are usually small, but taken as a whole they aggregate a large tonnage. As a rule, they are almost entirely undeveloped and for that reason and also because of their nature it is almost impossible to estimate the extent of the orebodies. In most cases development work should include drilling in order to determine the boundaries of the ore deposits. In some instances the drilling operations would best precede the opening up of the orebodies.

TONNAGE AVAILABLE AND EXPECTED

The iron ore reserves of the Northwest are not at all comparable with those of the east in extent. It is impossible to make any tonnage estimates within reasonable limits. That the ores of Alaska, British Columbia, Washington, and Oregon will be sufficient to supply the Pacific Coast markets for blast-furnace smelting for several generations at the present rate of consumption is quite certain. The available ore is estimated at 13,000,000 tons to 20,000,000 tons, and the tonnage expected at 60,000,000 tons to 110,000,000 tons. This last, however, cannot be considered as immediately available.

METHODS OF MINING

Mining methods should be carried on largely by open-pit and glory-hole methods. Some of the deposits will be mined by underground methods entirely, while practically all of them will require such methods after the surface ore has been removed down to a certain depth. Either stoping or block caving will probably be found most suitable as a rule.

CHARACTER OF THE ORES

The ores consist largely of magnetites which, generally speaking, compare very favorably in quality with the magnetites found elsewhere. Some of them are high in sulfur content, but practically all of the

magnetites are very low in phosphorus. They are usually hard and contain a rather high percentage of silica, and will therefore require a little larger proportion of fuel and fluxes than the average in smelting. One deposit of first class bog-ore is known to exist in British Columbia, but the limonite and hematite deposits of Washington are of an inferior grade.

THE UTILIZATION OF THE IRON ORES OF THE NORTHWEST

Many of the ores of the Northwest will require some preliminary treatment before they can be successfully utilized in the blast furnace. A large proportion, however, can be used without any preparation, while it will probably be found practicable to utilize most of the remainder in mixing with ores from different deposits.

CONCENTRATION AND TREATMENT OF ORES

Metallurgical experiments indicate that the pyritiferous and gangue-bearing magnetites are very satisfactorily treated by magnetic separation and that the dry method will be best adapted to the coarse grained ores like those found on Texada island, while wet separation will be best suited to the finer crystallized ores of Prince of Wales island, Alaska. It is also probable that the copper bearing magnetites will best be treated by a combination of flotation and wet magnetic separation, in which both the copper and iron may be recovered. It might be found most practicable in some cases to employ a combination of magnetic separators and concentrating tables. Roasting or sintering, and nodulizing of fines, particularly concentrates, will probably be advisable. The inferior bog ores and hematites of Washington could probably be improved by washing. Further investigation will be necessary before it can be determined whether or not the impure magnetites of the Northwest can be successfully treated on a small commercial scale.

COSTS OF MINING, MILLING AND TRANSPORTATION

The total cost of mining and transportation of ores to the blast furnace is estimated at \$2.50 per ton, which is conservative. Milling costs are not estimated, but they should not exceed \$1.00 per ton of concentrates produced, including sintering and agglomeration.

FUEL AND FLUXES

Coke suitable for iron blast furnace smelting can be manufactured in the Northwest in sufficient quantities to serve all purposes of any iron and steel industry which might be established here. The

coke will usually run rather high in ash and the quantity required in the production of a ton of pig iron will therefore be a little higher than the average. If the by-products are utilized the cost of producing coke will probably be from \$3.50 to \$4.00 per ton. Five dollars a ton should be a safe figure.

Charcoal which will meet all requirements made upon it for use in electrothermic smelting can be produced in sufficient quantity and at a reasonable cost.

LABOR

Labor, skilled in the iron and steel industry, is scarce on the Pacific coast at the present time. However, once an industry is established there should be no great difficulty in procuring an ample supply. Unskilled labor is plentiful and of a high quality. Wages are generally high, but the cost of labor per unit of output is not so high because of the better type of workman. The labor question should not hinder the establishment of an iron and steel industry in the Northwest.

COSTS OF PRODUCTION

The cost of producing pig iron on the Pacific coast will be rather high, but not excessive. It is estimated that pig iron can be produced in the blast furnace for \$13.50 to \$15.50 per long ton. The actual cost will depend upon the tenor of the ore used, the proportion requiring concentration, whether or not flue dust is recharged, etc.

A superior quality of charcoal pig iron should be produced in the electric furnace for about \$21.00 per metric ton. This is considered to be a safe figure. Certain favorable conditions affecting particularly the cost of power and charcoal will reduce this figure. If coke is used in place of charcoal the cost will be about the same.

MARKETS

Regarding markets it is evident that the present local demand is sufficient to support a modern iron and steel industry. The foreign market is small and, as yet, undeveloped. The markets are young and growing, and the establishment of a steel plant on the Pacific coast will bring about conditions which will greatly accentuate the expansion. The outlook for future markets is very encouraging.

Taking all factors into consideration and barring risks common to all iron and steel industries, the success of such an establishment located in the Pacific Northwest seems assured.

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UNIVERSITY OF WASHINGTON
BUREAU OF INDUSTRIAL RESEARCH

H. K. BENSON, Director

Eng. Exp. Sta. Series

BULLETIN NO. 13

An Industrial Survey of Seattle

BY

CURTIS C. ALLER

Research Fellow



SEATTLE

Published by the University
March, 1918

THE Bureau of Industrial Research of the University of Washington was established January 21, 1916. Its functions are: (1) The co-ordination of the several departments within the University that possess expert knowledge of a given problem; (2) the study of industrial problems which have a general part in the upbuilding of the State; and (3) the undertaking of investigations of primary interest to the individual or corporation proposing them. The work of the Bureau is controlled by the President of the University and a faculty staff selected to take charge of the various problems under investigation. Communications to the Bureau should be addressed to the Director, H. K. Benson, University of Washington, Seattle, Wash.

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BUREAU OF INDUSTRIAL RESEARCH

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BULLETIN NO. 3

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FOREWORD

VANDERVEER CUSTIS

The highest development of a modern industrial community is not a matter of chance. Neither can it be attained by the individual efforts of able men, each of whom is trying to build up a successful business for himself. Such men are essential, but to secure the best results all of them must have considerable knowledge of the industrial community in which the work is done. Some such knowledge every successful business man possesses. Few, if any, possess as much of it as they would like. The need of such knowledge is likely to be felt with special force when an established industry is contemplating expansion into new lines. It is commonly more strongly felt by a new concern that is just entering the field. Moreover, it is, generally speaking, to the interest of the industry already established to welcome and help the newcomer. Doubtless few of them wish to see new competitors establish themselves; but the newcomer will be a competitor for comparatively few. He is likely to supply an increased market for the products of a larger number, and for some he may furnish needed raw materials or partly finished products. If he enters an industry in which the need for an establishment is generally felt, he will be the more heartily welcomed. In any event, if his business be a desirable one he adds to the importance of the industrial community of which he becomes a part.

It was with such ideas as these in mind that the Seattle Chamber of Commerce and Commercial Club and the Manufacturers' Association of Seattle decided to establish an industrial fellowship at the University of Washington. It was arranged that this fellowship should be connected with the Bureau of Industrial Research of the University, but that the work of the fellow should be under the direction of members of the faculty in what is now the School of Business Administration. It was planned that the work should begin with an industrial survey of the city and that this should be followed by a series of studies devoted to particular industries. The results of the survey, aside from the business directory which is separately published, are herewith presented. The entrance of the United States into the war has, however, made it impossible for the present to undertake the studies of the separate industries.

The first holder of the fellowship was Mr. Curtis C. Aller, now a member of the National Army. Mr. Aller was a graduate of the

University of Washington in the class of 1916. He began his work on the industrial survey in January, 1917, and devoted almost his entire working time to it until the summer of the same year.

As the first step towards the information needed a questionnaire was mailed about February 1st to a tentative list of manufacturers. In many cases it was necessary to follow this questionnaire with personal visits, and as the information was desired promptly, a class of eight students, Juniors and Seniors, was formed to assist in calling on the concerns failing to give sufficient information by mail. Upon the declaration of a state of war by the United States, five of these men left college to enter the national service. This made it impossible to follow up as intensively as was desired firms that seemed unwilling to give information. Nevertheless, practically every concern not replying by mail was called upon at least once, and it is believed that the information collected is sufficiently comprehensive to be of considerable value.

When Mr. Aller left Seattle, the field work of the survey had, of course, been completed and the greater part of the report had been written. The editors found that the work had been so carefully done that there was little need for modification of it on their part. There were, however, some points which it seemed to them might well be eliminated, and this was done. In a few cases some modification of form seemed desirable. Certain changes were made in Chapter 4, as is indicated in the footnote to that chapter. The credit for the work, however, belongs almost entirely to Mr. Aller and his assistants. It is they alone who were familiar with the facts presented. The editors regret, however, that it was impracticable to submit the printers' proofs to Mr. Aller for final approval.

Chapter I

DISCUSSION OF INDUSTRIAL GROWTH

A comprehensive analysis of any industrial community involves a consideration of these factors:

1. MARKETS
 - a. Domestic
 - b. Foreign
2. RAW MATERIALS
3. TRANSPORTATION
 - a. Rail
 - b. Water
4. MANUFACTURING COSTS
 - a. Fuel and Power
 - b. Labor
 - c. Sites and Buildings
 - d. Capital and Banking Facilities
 - e. Water
 - f. Insurance.
 - g. Taxes

Industries may receive their inception from any one or a combination of these conditions. Our plan does not propose to discuss these various factors thoroughly and apply them to our industrial life, but rather to point out how industries located in Seattle have profited from one or a combination of favorable conditions to such an extent that large industries have sprung up and are continuing to progress. Special reference will be found under the discussion of classified industries, which follows, on these various points.

For purposes of convenience and analysis the industrial world has been divided into four groups and names applied to them which seemed most characteristic of the group. These groups are "basic," "grouped," "market" and "trade."

1. "Basic" industries comprise those industries which depend upon the raw material and the natural advantages of the community. The first industries of any community to develop are always "basic," but it does not follow that all the "basic" industries develop before other forms of industries start. Lumbering is a "basic" industry of

the Northwest, and because of the many natural advantages surrounding the forests of the Northwest it has been the first great industry to be developed here. An industry which seems to have a natural place in the Northwest is the production of iron and steel;* the ores and the coal for coke are here, but due to many disadvantageous circumstances it has failed to be unlocked. It is highly probable that the large demands of the Northwest at present for iron and steel will, so to speak, force the beginning of this industry, and thus another "basic" industry will be opened. From the standpoint of economical value to the community, it can now be seen that "basic" industries are of exceptionally large value, for they are at the bottom of things, and with their coming a coterie of subsidiary industries follow.

2. "Grouped" industries are those whose life depends upon the existence of "basic" industries. They may or may not be founded upon the raw materials available in the territory where they grow up. With the starting of a sawmill in a community an immediate need is created for sawmill machinery. In the first instance, this machinery must come from established manufacturing centers. As the lumbering industries progress more and more machinery is needed, and the demand in time will become great enough to warrant the manufacturing of sawmill machinery in the new community. The first attempt at manufacturing to supply the demand for sawmill machinery will be in the form of custom foundries and machine shops building to the specifications of the wants of lumbermen. In time, as the wants of sawmills increase, it becomes practicable to manufacture a special line of sawmill machinery, and to carry this machinery in stock. Thus a modern factory with specified products is built. Another growth of "grouped" industries is where an entirely new invention is made to take care of the wants of "basic" industries, and the manufacturing of this machinery is put on a modern factory system at once. A case in point has been the growth of the manufacture of fish canning machinery in Seattle.

3. "Market" industries are those industries which supply a manufactured commodity for the immediate consumption of the people. This group includes such lines as shoes, cloaks, etc. This group, like the others, can be divided into stages of growth; as for example, the coarser grades of shoes, such as loggers' and miners' shoes, were the first to be made in Seattle, and then the manufacture of the higher grades of ladies' and men's shoes.

* Bulletin 2, "Iron Ore Resources of the Pacific Northwest," published by the Bureau of Industrial Research.

4. "Trade" industries are those which, because of a highly developed industrial condition—namely, a high stage of the utilization of local raw materials, stabilized labor market, etc.—manufacture articles depending upon the supply of the world at large for raw materials, and likewise upon the markets of the world to sell their finished products. The fullest realization of this condition means the use of a free port district, as exemplified in Hamburg, Germany.¹

Besides these classified industries there are industries which may be better designated as "specialties." They are represented in new ideas which take the form of patents. They are made, as a rule, in highly centralized manufacturing centers. An example of a special commodity made in Seattle and marketed all over the world is electrical wireless apparatus.

This discussion is made to show how industrial development progresses. The classification as given represents the progressive stages of industrial growth. An application of the above principles to Seattle will show her present industrial position, and at the same time will show the wonderful opportunities before her.

A glance at the statistics prepared by the Bureau of Industrial Research of the University of Washington reveals Seattle's leading industries, in the order of their importance, for 1916 as follows:

1. Meat Packing
2. Shipbuilding
3. Flour Milling
4. Lumbering

This order of importance will be changed this year [1917], as the shipbuilding will far surpass any other, both in value of finished product and the number of persons engaged in any one industry. Neither will this order hold for Western Washington as a whole, as lumbering has been first for many years.²

Every one of Seattle's leading industries are "basic" in that they depend upon the natural resources of the immediate surrounding territory.

Seattle, however, has made a creditable start in the manufacture of "grouped" industrial products, as verified by the commodity index of the *Industrial Directory*.³ Among these "grouped" industries are

¹See "Seattle an Industrial City," p. 26, by Paul P. Whitman. Published by Industrial Bureau, Seattle Chamber of Commerce and Commercial Club.

²See Lumber, in this paper.

³Published separately by the Manufacturers Association of Seattle, 1918.

foundries with special products, as plumbers' brass hardware, and machine shops with special lines of machinery, as sawmill machinery and fish canning machinery.

Sometimes the contention is made that Seattle can manufacture only what the "big fellows" in the East will let her, but this contention is not entirely borne out, as shown by the facts. True enough, practically every one of the products of the "grouped" industries is manufactured by the Eastern manufacturing centers on the large scale of modern factory methods near the base of supply of raw materials, and with many other advantages; yet, in spite of these things, Seattle's "grouped" industries have prospered in the past and are continuing to grow. The one big advantage for many lines is that Seattle manufacturers are near the markets for their finished product. This is a differential which has spelled success for many firms in the past and which augurs well for the future, for they are in a growing market of unforetold possibilities. In "market" industries Seattle has made a very favorable start. At the present time she has six shoe factories, one of which makes high-grade ladies' and men's dress shoes. Additional products made by factories in this grouping are ladies' and children's garments, cloaks, neckties and other products of a similar nature. With an increasing population in the Northwest, the size and number of this class of factories will be largely increased.

"Trade" industries hold for Seattle large opportunities for development in the future, for one of the first requisites in this group is transportation facilities. That Seattle has these facilities, and that they are increasing, is attested to by the customs reports on her commerce, the most recent of which gives her first place on the Pacific Coast. With the growth of a United States merchant marine this trade will be established with an increased assurance, and the growth of population and wealth which will come therefrom will bring forth the realization of an apparently idle dream.

OPPORTUNITIES FOR FUTURE INDUSTRIES

Seattle's growth has been a succession of periods of phenomenal expansion and prosperity. While originally her prosperity was based on the lumber industry, her advantages as the mart of the great Alaskan trade and the rich back territory of Washington, Oregon, Idaho and Western Montana gave her an impetus of development which earned for her the right to be known as the Metropolis of the Northwest. An examination of present-day happenings makes it apparent that her future lies in the development of two equally great opportunities—her foreign trade with the Orient and her domestic

trade, and her industrial development. In so far as one of these becomes predominant with a neglect of the other, she suffers in the realization of the fullness of her opportunities. Today Seattle is a commercial center, but it is believed that the suggestions of possible future industrial developments contained herein will bring to the mind of Seattle forcibly her industrial opportunities which are equally as great as her commercial future, and thereby reap the fullness of her destiny.

While this investigation was being made, statistics published by the United States Customs Service showed that Seattle had taken first place in foreign commerce on the Pacific Coast; and the last year has witnessed the birth to the lumber industry of the sister industry of shipbuilding, equally as large as itself. The latter part of this statement is borne out by the last figures obtainable on the lumber industry. *United States Census Report 1909* gave the value of the production of lumber at \$89,000,000; and the estimate available on shipbuilding industries of Washington for 1917 place the output at a value between \$75,000,000 and \$100,000,000.

As an index of the type of development it is of interest to note the following list of recent sales and leases of Seattle waterfront property for industrial purposes:

Individual or Firm	Location	Acreage Front		Value	Use
Skinner & Eddy	E. Waterway	25	900	\$2,000,000	Shipbuilding
Duthie & Co.	E. Waterway	11	800	300,000	Shipbuilding
Ames Shipbuilding Co.	W. Waterway	12	1,200	300,000	Shipbuilding
Wash. Shipping Corp.	W. Waterway	12	800	300,000	Shipbuilding
Commercial Boiler Wks.	E. Waterway	1.5	100	50,000	Boiler
Dungeness Logging Co.	E. Waterway	3	250	60,000	Mill
Nat. Eng. & Equip. Co.	Duwamish W.	4	600	12,000	Engine Wks.
Pacific Coast Forge Co.	W. Waterway				Forge Wks.
Internat. Shipbldg. Co.	W. Waterway				Shipbuilding
Allied Shipping Inter.	W. Waterway	40	3,200	300,000	Shipbuilding
Elliott Bay Shipbldg. Co.	W. Waterway				Shipbuilding
Erickson Shipbldg. Co.	W. Waterway				Shipbuilding
National Canning Co.	W. Waterway	1.17	120	20,000	Canning
Whitman Lumber Co.	W. Waterway	1.5	120	30,000	Mill
Drummond Lighter. Co.	W. Waterway	1	80	20,000	Tugboat
Neider & Marcus	W. Waterway	1	120	10,000	Machine
Patterson & McDonald	Duwamish	25	2,500	200,000	Shipbuilding
Pacific Shipbuilding Co.	Duwamish	7	960	50,000	Shipbuilding
National Shipbldg. Co.	Duwamish	7	600	40,000	Shipbuilding
Newell Mill Co.	Duwamish	14	1,000	20,000	Mill
Yakima Sheep Co.	W. Waterway	1	240	30,000	Packing
Olson & Son	Duwamish	8.75	1,300	40,000	Shipbuilding
Clemenson	Duwamish	4.1	290	20,000	Shipbuilding
Meier	Duwamish	8	600	10,000	Oil
Pacific Products Co.	Duwamish	3.5	250	18,000	Factory
Otto Case et al.	Cedar Street	2.5	165	75,000	Shipbuilding
American Canning Co.	Salmon Bay	6	410	100,000	Tin Cans
Frank Waterhouse & Co.	Lake Union	2	225	40,000	Bunkers
Libby, McNeil & Libby	Lake Union	3.33	725	25,000	Cannery
McKinney Brothers	Lake Union	1	160	10,000	Boats
Republic Creosoting Co.	L. Washington	70	1,000	75,000	Treat. Piles
Sandstrom Shipbldg. Co.	Meadow Point	10	480	25,000	Shipbuilding
Orvis Lumber Co.	L. Washington	12	1,000	40,000	Mill
N.W. Spar & Flagpole Co.	L. Washington	1	170	10,000	Spars
W. E. Boeing	Duwamish	2	300	10,000	Factory
Anderson Shipbuilding	L. Washington	12	600	10,000	Shipbuilding
		336.5	24,405	\$4,635,000	

To mention shipbuilding only is to forget the large development in other lines of industries. There have been established also new forging factories, machine shops, a galvanizing plant, and an additional shoe factory. New industries for Seattle have also been started for the production of lead pipe and lead specialties, and of nitrogen products from the air by means of the cheap electric power of the Northwest. In addition to this old factories have enlarged their plants to take care of increased demand, or have secured different sites on which to build new factories.

With an eye as to future development of Seattle, two questions were included in the questionnaire*—the first to point out possible opportunities for new factories, and the second to point out the difficulties and needs of the present industries. The first question was: "Articles which in your opinion should be manufactured in or near Seattle, and reasons why such articles could be produced here at an advantage." The answers to this question are classified under the same group heads as used in the description of industrial growth.

The chief beauty of this classification is that it crystalizes the facts how industries grow; and it would seem that it could be used to point out possible future developments.

Our shipbuilding activities are based upon the lumber resources of the State. The wooden shipbuilding industry has created a demand for galvanized bolts and nuts. Several shipbuilding firms in answering this question suggested the need for a galvanizing plant. This need became so great that a company was incorporated to operate such a plant, which began operation the first of June. Investigations are also being made by different parties to see if the demands warrant a second factory using the sherardizing process of galvanizing instead of the hot dip process as used by the present operating firm. A factory to make small drop forgings, and another to make heavy marine forging, have started operation to take care of the shipbuilding demands. Other subsidiary shipbuilding industries promise to be started inside of the next few months—for example, a factory to make marine oil engines.

Another example of how industries in their growth build new industries is found in the large use of steel plate by the steel shipbuilding companies now operating in Seattle. This demand, coupled with the requirements of other users of iron and steel, has brought to the attention of local men the crying need of the development of

* See Appendix, p. 59.

the iron and steel industry on the Pacific Coast.* In passing it will be well to mention that the establishment of such an industry would mean the development of scores of subsidiary industries; among them, tin plate, various lines of machinery, textile industry and others of like importance. The following suggestions which were received in answer to the question of opportunities for new factories are offered without comment:

1. "BASIC" INDUSTRIAL PRODUCTS

- Glucose
- Heavy Chemicals
- Paper
- Pig Iron
- Potash
- Pulp Board
- Rolled Copper
- Steel Plate, and other Rolled Steel Products
- Smelters
- Woolen Goods

2. "GROUPED" INDUSTRIAL PRODUCTS

- Brass and Bronze Products
- Brass Plumbing Goods
- Machinery
 - Mining
 - Marine
- Marine Oil Engines
- Malleable Iron Castings
- Oak Tanned Leather
- Soap
- Tin Plate
- Woodenware Products, including Furniture

3. "MARKET" INDUSTRIAL PRODUCTS

- Chocolate
- Matches
- Music lithographing
- Clothing of various kinds
- Rattan Furniture

4. "TRADE" INDUSTRIES

* Bulletin 2, "Iron Resources of the Northwest," published by the Bureau of Industrial Research. 1917.

No suggestion embodying the total realization of the last named class of industries was received. Mention, however, was made of the use of raw materials found in the Orient. Among these were the possible use of China pig iron, Siberian oak and Philippine hardwoods. Without doubt these materials, and many others from the Orient, will be used in the manufacture of products in the Puget Sound territory. These industries depend largely upon an assured ocean carrying trade. This is not an impossibility, as evidenced by the contemplated line of steamers through the Panama Canal to carry iron over from the mines of the Bethlehem Steel Company in Chile to its plants on the Atlantic Coast. If companies in other parts of these United States are able to accomplish such undertakings, it will be a queer thing if a district like Puget Sound, with equally as good advantages, cannot do similar things.

COMPARISON WITH OTHER COAST CITIES

A comparison of Seattle's industrial status with other Coast cities represents a very important phase in the consideration of present and future industrial conditions, as a comparison with rivals helps to give a larger knowledge upon which to work. If through such a comparative study the strong and weak points of rivals may be brought out, suggestions can often be made which will be of much value in the future, either where competitive or non-competitive industries are established or are likely to be established. This comparison is not intended to be comprehensive, but only to call attention to facts which were picked up by personal contact.

The only Coast city which seems to have a more advanced condition of manufacturing than Seattle is San Francisco. She has in the way of factories what Seattle has not: leather tanneries, soap factories, a glue factory, a carbon-paper manufacturer, chocolate manufacturers, etc. In some instances San Francisco depends upon this territory for raw material to supply the aforesaid factories, and also depends upon this territory for a market for the finished products of the same plants. Seattle meat packers ship offal to San Francisco soap factories, which return the finished product to this territory. The same is true of hides and leather.

Sometimes the contention is heard that cigars cannot be made in Seattle, and so it would seem from the decrease in the number of cigar manufacturers in the last two years, because the production of cigars depends so largely on the cultivated tastes of the consumers,

and from the standpoint of the manufacturer requires large investments in advertising with uncertain results. Typical of the Californian spirit, San Francisco in this once instance has been able to conquer a seeming impossibility in manufacturing. She has been able to do this through fostering the spirit of patronizing home industry. The result has been that one cigar factory is enabled to keep 250 employes at work.

Portland is noted for her furniture, and it is highly probable that she will continue to hold her own in this line.

There are instances of well established woolen mills in Oregon and California, while there is only one in this territory, with a very limited output. There are also several paper mills up and down the Coast, and none in this immediate neighborhood.

In the encouragement of the establishment of new plants here the important thing is to decide whether the territory will warrant a rival factory to the already established Coast factories, or to give the entire attention to establishments of industries not yet developed on the Coast.

DIFFICULTIES IN THE WAY OF MANUFACTURERS

Through answers to the question asking whether organized assistance was desired in the solution of certain problems, and by personal contact, several difficulties were brought out.

One of these is the lack of consumption of local-made products. Complaints were made most consistently by cabinet makers, cigar manufacturers, garment and cloak manufacturers and printers. Another difficulty is the lack of a thorough communal interest in manufacturing. This sentiment is expressed chiefly by the small firms. This spirit seems to be reminiscent of the spirit which predominated Seattle for years. This spirit may be called the commercial spirit. Seattle's growth has been fostered and nurtured to its present size largely under the influence of trade and commerce. Large fortunes have been massed through efforts devoted to trade and commerce. Seattle has been so imbued with the success of commerce that her communal efforts have been devoted almost entirely to the adjusting of trade conditions and building for future trade development.

It is a fact that large Eastern firms with branches in Seattle have in some instances been able to stifle the local factories that have attempted to establish a competitive business. Another fact to which attention is invited is the demand for capital by local firms. Manu-

facturing firms, more particularly the smaller and medium-sized firms, but in some instances firms doing more than \$100,000 business a year, have experienced much difficulty in borrowing money. It is often difficult to borrow for purchases of raw material, and practically impossible to secure capital for plant development. This is not entirely a local grievance, as the principles on which banks loan money make this a problem in nearly every community. This may, however, be a local problem, in so far that most of the available capital goes to satisfy the demands of commerce.

Besides these difficulties there are questions concerning labor, transportation rates and facilities, taxes, foreign trade, and others of a specific or individual nature. Attention is merely directed to these by mentioning them, as it is believed that the public is generally alive to them and that much communal effort is being directed for bringing about a better condition.

Attention is called to these few facts not because they are typical of prevalent conditions, but merely to emphasize the fact that such conditions were encountered. To what extent these difficulties are working an evil or handicap is hard to say. In contradiction to the above mentioned difficulties, it seemed that in every case where an energetic man of the right caliber was behind the guns, that that plant was going ahead. Then, if this be true, what is needed most is the right man in the right place.

Chapter II

GENERAL STATISTICS OF SEATTLE INDUSTRIES

The figures presented in Table I. (p. 18) are not comparable in ratio to the figures issued by the government, yet enough is presented so that the comparisons can be made to show forcibly the picture of Seattle's industrial life, where it has had decline and where it has had wonderful growth. As a general rule, those industries depending upon building activities of Seattle and nearby towns show a decline, as well as a total loss of the liquor business, while, practically speaking, all other industries have increased their output, and have greatly increased their force of employees. Specific references to declines and to increased productions will be made in the discussions under the classified industries.

So that the reader may judge of the accuracy of the data presented, the method of how the data were secured is given. About 100 firms furnished complete information by mail in answer to the questionnaire* and letter mailed to them. The balance of the information was secured by enumerators, or was mailed to us after the solicitation of an enumerator. Firms in giving information were asked to give exact figures, or in case they did not care to do so to give conservative estimates. The large firms usually furnished the data from their accounts, while the small firms had to resort to estimates, inasmuch as nearly all of them failed to have an accounting system. It seems needless to mention the importance of a well-kept set of accounts in manufacturing, yet the number of instances found where only attempts were made at accounting shows a lack of appreciation of its real value. It is a servant of no mean value, and its use means in the end increased profits. Rather than a system whereby to determine the amount of profits, accounting gives a complete record of every business transaction, and above all a knowledge of the cost of production to be obtained in no other way.

In the compilation of the statistics the greatest care was taken to use only figures which would indicate accuracy. Questionnaires which showed clearly a misinterpretation, or incompleteness, were discarded in the compilation of the tables. In the very nature of the

* See Appendix, p. 59.

TABLE I—SUMMARY OF TOTALS, SEATTLE INDUSTRIES, FOR 1916

	No. of Firms	Reporting Firms	Persons Engaged in the Industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	Invested Capital	POWER						Cost of Power and Fuel
										Reporting Firms	H. P.	Reporting Firms	Steam H. P.	Reporting Firms	Both Steam and Electric H. P.	
All Industries																
excluding Out- side Factories.	959	682	18,221	517	\$29,661,756	631	\$86,264,785	611	\$30,462,829	512	17,657	26	6,860	8	3,102	\$586,903
Chemicals	43	30	233	21	364,158	29	988,004	22	769,900	15	166	3	395	...	...	7,971
Food Products	155	105	3,359	76	16,874,070	97	35,832,261	91	11,751,150	82	5,272	2	800	5	...	181,554
Iron and Steel	131	96	2,337	74	3,039,322	86	6,709,747	87	2,830,830	87	3,337	1	80	3	705	82,593
Leather	20	20	408	17	1,452,492	20	2,212,398	19	848,600	17	224	...	...	2	262	6,053
Beverages	14	10	66	3	63,200	6	234,264	9	178,900	8	72	...	...	...	...	5,157
Lumber and Re- manufactures.	95	77	2,482	55	3,295,578	77	7,851,658	71	4,475,427	56	5,038	13	4,630	2	1,165	59,439
Metal Products other than Iron and Steel	89	66	567	47	671,061	55	1,649,664	55	487,300	35	730	...	...	...	...	10,088
Printing and Al- lied Industries.	134	102	1,425	91	1,108,134	102	3,531,664	101	1,391,440	96	761	...	...	...	...	23,398
Shipbuilding, Steel and Wood Boat Bldg., Drydock- ing, & Repairing.	29	20	3,995	16	363,091	17	14,784,915	16	734,450	...	...	...	...	...	...	...
Stone, Clay, Glass Products, ex- cluding Cement.	30	23	794	14	146,742	22	1,280,083	21	3,373,300	16	832	5	565	...	...	167,216
Textiles	64	53	1,422	41	1,645,356	48	3,398,302	49	1,067,390	47	386	...	...	...	...	10,394
Cigars	7	5	65	4	59,000	4	114,200	5	42,100	...	...	...	...	...	...	...
Vehicles & Parts.	24	22	450	14	299,175	16	5,944,437	15	788,500	18	331	...	...	...	...	10,296
Miscellaneous ...	118	53	498	34	280,077	52	1,733,138	50	1,353,542	36	508	2	390	...	...	22,044
Out of City Fac- tories—																
Cement	3	3	357	...	...	3	1,420,896	3	3,900,000	3	7,000	...	...	...	...	284,986
Lumber Mills....	16	6	1,795	4	1,015,000	6	2,685,250	5	3,797,000	...	...	4	3,010	2	5,000	...

case misinterpretation of questions was bound to occur, and in the estimates which were secured there are always inaccuracies. But in the aggregate these errors will largely offset each other. One man will overestimate and another man underestimate for diametrically opposite reasons. In addition to this, the totals are largely made up from large firms giving information from their accounts, in which case gross errors introduced by the estimates of smaller firms are almost entirely done away with. In all, there were over 800 firms answering the questionnaire either in detail or partially. Of this number about 700 are used in the compilation of the statistical tables.

The presentation of statistics is so arranged to get as near as possible a comparable relation with the government statistics. In giving statistics for the subgrouping of the classified industries, before the totals for each question the number of firms responding is given. In order to get a comparison between the various columns, the firms furnishing complete information are given first, and then firms giving partial information, followed by the total of the two. In a few instances the order of this rule is broken to keep from revealing individual operations. Likewise, in Table I this rule is not followed, because it is believed immediate totals for each question are of more value than a comparison between the different columns.

Of the statistics presented, it is believed that those relating to the number of "persons engaged in the industry" in all the tables included in this report are as accurate as those prepared by the government. It is seldom, if at all, it is believed, that a firm would have any cause for misrepresentation of the number of persons engaged by them; and there is very little chance of inaccuracy, as the number of persons engaged is easily obtainable. In the case of answers to the other questions, it is different for reasons mentioned before. Even in the case of the "value" of the finished product, on the basis of the previous discussion, it appears that a comparison can be made which for all practical purposes would be within the bounds of fair approximation. One factor which, however, must be considered is the inflation of prices caused by war conditions. This is incalculable, and no deduction can be made for it.

A comparative study of Seattle manufactories issued by the United States Census Bureau for 1914 and those prepared by the Bureau of Industrial Research of the University of Washington reveals large increases:

	U. S. Census 1914	Bureau's Census 1916	Per Cent. of Increase 1914-1916
Number establishments.	1,014	1,149	13.3
Persons engaged in man- ufacture	15,761	20,194 to 22,000	28.1 to 39.5
Value of products.....	\$64,390,000	\$92,907,785 to \$100,000,000	44.4 to 55.3

The figures on the value of raw materials are of no comparable value whatever in the totals with the United States Census, due to the fact that they are so incomplete. Manufacturers either were reluctant to give this information, because they thought it would reveal their business conditions too much, or were unable to do so because of a lack of well-kept cost accounts. The purpose of including this question was to obtain the value added by the manufacturer, which represents the economic value of the industry to the community in the form of wages, rents, profits, etc. However, the data which were secured along with the information of the kind and sources of raw materials is of a very valuable nature in making future investigations. Aside from this, where complete data permit of ratios between the value of the raw material and the value of the finished product, the ratios so obtained fall within a 5% variation of those obtained by United State Census.

Examples:

Flour Mills

United States Census, 1909, for entire United States.....	86.7%
Bureau's statistics, 1916.....	81.0%

Printing

United States Census, 1909, for entire United States.....	27.3%
Bureau's statistics, 1916.....	31.8%

Further comparisons show similar likeness, all of which is a strong argument for the accuracy of the statistics presented by the Bureau of Industrial Research.

The statistics of capital are very incomplete and defective, and, in fact, almost worthless. In the first place, firms who know the exact amount of capital invested on any date in their business are reluctant to tell it. Defectiveness of various kinds as enumerated below creeps in:

1. Many concerns have no capital account, particularly true of the small establishments.

2. Capital invested in buildings and machinery always depreciates as a result of wear and tear unless maintained by further expenditures.

3. The invention of new machinery, the opening up of new supplies of raw materials, or other changes in the conditions of production, or changes in demand may render worthless an investment in a manufacturing enterprise, or greatly reduce its value.

4. Real estate owned by establishments have large fluctuating values.

5. Some corporations engaged in manufacturing give their capital stock as their investment.

6. The capital reported may or may not include value of stocks of materials and of finished or partially finished goods, accounts, receivable, cash, etc.

Under the grouped headings of industries the item of "goods consumed in Seattle and King County" is obtainable always by taking the ratio between the value of the output and the amount consumed locally of those firms giving data. The number of firms reporting a percentage of outside business is given without the bases upon which this percentage is calculated. While it would be desirable to have these bases so a better judgment of the representativeness of the percentage for the commodity could be formed, it seems unnecessary. A comparison of the number of reporting firms for "percentage consumed in Seattle and King County" with the number of reporting firms of "value of finished products" shows that nearly the same number report in each instance. Where a less number report for "percentage consumed" locally, an inclusion of their figures would not materially alter the result, as a study of the general data shows such failures to occur among the small firms. And again, the percentage of local consumption as given by the firms are only guesses, and not accurate calculations. Consequently, it appears, that the result given would be fairly representative of the real situation, and give a good idea of what this question was designed to show—namely, a fair approximation of the extent to which local manufacturers depend upon the local market to sell their goods.

The statistics which are presented on the amount of installed horsepower apparently show a decrease as compared with the United States Census figures for 1914. There was, in fact, no such decrease, as a study of the data from which they have been compiled shows that

many large users of power, such as shipyards, failed to report the amount of installed horsepower. A closer analysis shows that no data at all was secured from several establishments which are large users of power—namely, four lumber mills, one shingle mill, one steel mill, and two ice plants, etc.

The importance of power in manufacturing is vital for the existence of many industries. From the standpoint of kind of power, cheapness, cleanliness, etc., it would be pertinent if a ratio between the amount of steam and electric power used could be obtained. Even this inability to obtain definite ratios does not destroy the value of the data, for an examination of the statistics reveals many interesting and valuable things about the use of power. Among these is the fact that a large amount of primary electric power is used by lumber mills. At first this does not seem reasonable, inasmuch as lumber mills have large amounts of waste material. Yet in those instances where electrical power is used instead of steam in lumber mills, it is claimed by the users to be much cheaper than the maintenance of a steam plant, with additional advantages of cleanliness, and ease of transmission of power. A further study of the tables will reveal similar conditions where steam power is ordinarily used. The use of electrical power to such a large extent in Seattle is made possible by its great cheapness, there being only one other place in the United States with cheaper electrical power, namely, Niagara Falls.

To show the power facilities of the Northwest the following table, from a report of the College of Engineering of the University of Washington, to the Washington Legislature of 1917 is given:

POWER FACILITIES IN WASHINGTON AND ITS DISTRIBUTION

	Western Wash.	Central Wash.	Eastern Wash.
Number hydro-electric power plants.....	22	16	16
H.P. of hydro-electric power plants.....	146,000	21,000	140,000
*Undeveloped hydro-electric power..... (Full year, 24-hr. day, cost of development less than \$150 per H.P.)	1,306,000	418,000	120,000
*Undeveloped hydro-electric power..... (Less than full year, 24-hr. day, cost limit not specified)	6,285,000	800,000	240,000
Number steam power plants.....	43	9	8
H.P. of steam power plants.....	46,000	4,000	22,500

* Exclusive of Columbia River and rivers without available data.

The cost of power and fuel, as given in the statistical tables, is not representative of what is the truth in manufacturing. Too many firms failed to give the cost of power and fuel. Sometimes the kind of fuel

was given without cost, or again the amount of costs was given without kind of fuel. The reason which explains the above is the fact that in giving both figures, amount of fuel and cost, firms which are large users of fuel would reveal thereby any special contracts which they might have, and the medium sized and small firms seldom had the data for this item in an available form. The data are included, however, as having some value in suggesting vital and important questions of the use of fuel in manufacture.

It seems well to include at this point tables showing estimated totals for the number of firms operating in Seattle, number of persons engaged in manufacturing, and the value of the production for the year 1916. By comparison with the United States Census for 1914, where the Bureau's data are incomplete, estimates are made. It does not appear possible that with an increased population a decrease has occurred in the output of bakeries, and likewise for printing and publishing. The Bureau's statistics leave unaccounted for about 95 bakeries and about the same number of publications. The industrial survey includes only bakeries doing a wholesale or a wholesale and retail business, and likewise does not include the various trade journals, weeklies and semi-weeklies and other similar publications. By adding the number of these firms to the number accounted for, an approximation of 1,149 firms operating in Seattle in 1916 is secured. The difference between the Bureau's figures for 1916 and the Census figures for 1914 of the bakeries and printing and publishing industries for "value of finished product" and "persons engaged in the industry" is included in the approximation of estimated totals.

TABLE II—ESTIMATED STATISTICS

	Number of Firms	Persons engaged in the Industry	Value of Finished Product
Seattle industries (from Table I)...	959	18,291	\$86,264.785
Estimates from firms not reporting.	190	1,903	6,643.000
Total	1,149	20,194 to 22,000	\$92,907.785 to 100,000.000

The highest approximation is calculated by adding about 10% to the values obtained as explained in above table. The knowledge at hand of firms not reporting would lead to the belief that the above approximations are very near the truth.

TABLE III—CHEMICALS AND ALLIED INDUSTRIES

	No. of Firms	Reporting Firms	Persons engaged in the industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Product	Reporting Firms	Percentage consumed in Seattle and King County	Reporting Firms	Capital Invested	POWER				FUEL		Cost of Power and Fuel
												Report. Firms	Electric. H.P.	Report. Firms	Steam H.P.	Report. Firms	FUEL	
All Chemical Products	43	30	253	21	\$364,188	29	\$988,004	22	.....	22	\$769,900	15	156	3	395	2	.....	\$7,971
Druggist Preparations	16	6	16	6	27,850	6	79,950	5	.....	5	59,800	3	11	1	.....	2	Gas	418
Partial Reports	10	10	16	6	.....	1	3,000	.....	.....	.....	.....	3	11	.....	.....	2	Gas	418
Total	10	10	32	6	27,850	7	82,950	5	40	5	59,800	3	11	.....	.....	2	.....	.....
Paints and Varnish	4	4	69	4	158,464	4	256,225	.....	.....	4	410,000	3	63	.....	.....	2	Coke, Oil	923
Partial Reports	1	1	4	.....	.....	1	2,694	.....	.....	.....	.....	3	63	.....	.....	2	Coke, Oil	923
Total	5	5	73	4	158,464	5	258,919	4	45.0	4	410,000	3	63	.....	.....	2	.....	.....
Coal Tar Products	2	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Lubricants	4	4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Soaps	4	4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Miscellaneous (itemized)	10	6	60	3	45,574	5	118,885	5	.....	5	179,500	2	27	2	220	4	Coal, Gas, Wood.	1,734
Misc. (not itemized)	8	8	42	8	132,300	8	252,250	8	.....	8	120,600	6	15	1	175	3	Gas, Oil, Coal...	4,896
Partial Reports	4	4	46	.....	.....	4	275,000	.....	.....	.....	.....	1	50	.....	.....	.....	.....	.....
Total	18	12	88	8	132,300	12	527,250	8	.....	8	120,600	7	65	1	175	3	Gas, Oil, Coal...	4,896

Chapter III

STATISTICAL TABLES OF CLASSIFIED INDUSTRIES

CHEMICAL AND ALLIED INDUSTRIES

A few companies sell their products in the markets of the world; others, whose products are more of a sectional nature, as mixed paints and lubricants, draw upon the Northwestern states for their markets.

The raw materials are secured from Eastern centers, except in the case of a few companies which are established here primarily because of nearness to the source of supply.

One company recently organized is manufacturing nitrogen compounds from air. It is established here because of the cheap electrical power. All indications are that the next few years will see large expansions in the chemical industries, both in the output of the present factories and in the increases of new lines which utilize the large natural resources of the Northwest.

TABLE IV—Food Products

	No. of Firms	Persons engaged in the Industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	P.C. consumed in Seattle & King Co.	Reporting Firms	Capital Invested	Reporting Firms	Quantity	Reporting Firms	Electric H.P.	Report. Firms	Steam H.P.	Report. Firms	Both Steam & Electric H.P.	Report. Firms	FUEL	Report. Firms	Cost of Power and Fuel
All Food Products...	155	103,359	76	\$16,874,070	97	\$35,832,261	...	...	91	\$11,751,150	...	...	...	825,272	2,800	5,970	...	...	...	...	...	\$181,554
Baking Powder, Coffee, Extracts...	19	5,211	5	729,000	5	1,365,000	5	28	5	473,000	...	...	...	136	...	...	...	...	...	1 Gas & Gasoline.	4,778	
Bread and Bakery Products...	19	185	19	397,500	19	680,571	...	all	19	178,300	...	...	...	82.5	...	...	...	...	...	17 Coal, Gas, Wood.	12,340	
Partial Reports...	11	116	11	172,300	11	631,750	...	all	8	29,000	...	...	...	6	...	...	...	...	...	11 Coal, Gas, Wood.	6,895	
Totals...	37	30	30	659,800	30	1,312,321	37	all	27	207,300	...	...	...	23	110.5	...	...	...	...	28 Coal, Gas, Wood.	19,235	
Butter...	4	118	4	...	4	192,500	...	...	3	3,050	...	...	...	4	337.725	...	...	...	...	3 Coal, Gas, Oil.	9,312	
Partial Reports...	10	132	4	972,560	7	1,151,826	...	...	5	360,000	...	...	...	3	20	...	...	...	...	1 Coal, Gas.	398	
Totals...	10	132	4	972,560	7	1,344,326	...	...	5	413,050	...	...	...	7	336	...	...	...	...	4	9,710	
Confectionery—Products, including Ice Cream, Biscuits and Nuts...	...	14	376	950,944	14	1,509,944	...	...	13	439,000	...	...	...	12	316.5	...	...	...	...	13 Coal, Coke, Gas, Oil, Wood.	15,385	
Partial Reports...	8	388	1	45,000	3	59,000	...	...	5	110,000	...	...	...	5	895	...	...	...	...	2	1,546	
Totals...	41	22,744	15	995,944	17	1,568,944	11	56	18	549,000	...	...	...	17	406	...	...	...	...	15 Coal, Coke, Gas, Oil, Wood.	16,931	
Flour, Feed & Cereal Millers...	13	11	706	9,243,920	11	11,381,711	10	17	11	6,635,800	5	1,182,306 ²	10	3,417	...	1	450	...	...	1 Oil.	72,777	
Food Preparations...	...	7	98	431,258	7	673,797	...	...	7	378,000	...	...	...	5	44.75	...	2	120	...	6 Coal, Gas, Wood.	3,187	
Partial Reports...	13	116	7	431,258	11	699,937	9	51	9	384,000	...	...	...	3	4.5	...	...	...	...	2 Coal, Gas, Wood.	204	
Totals...	13	36	2	89,588	3	147,222	2	40	3	83,000	...	...	...	3	68	...	...	...	...	8 Coal, Gas, Wood.	3,391	
Macaroni Products...	4	3	3	...	3	...	...	...	3	...	...	...	...	3	...	...	...	...	...	...	2,441	
Meat Packers, including Sausage...	...	6	879	1,940,000	6	15,168,000	5	25	5	1,989,000	...	...	...	4	531	...	1	1,600	...	...	8,995	
Manufacturers—Fisheries...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
Fruit & Vegetable...	...	...	...	...	...	...	...	1	4	...	...	...	...	6	...	...	...	...	...	...	...	
Canneries...	...	4	9	4,000	3	9,800	...	2	8	...	...	...	...	5	218	...	1,200	2	400	...	...	
Miscellaneous...	...	8	434	1,902,000	7	2,844,800	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
Totals...	3	8	434	...	7	...	...	...	8	1,017,000	...	...	...	...	...	...	...	...	...	...	Coal & Gas.	898
																					43,596	

¹ Pounds. ² Barrels of Flour. ³ Tons of Feed.

898
43,596

FOOD PRODUCTS

The production of food products, such as flour, packed meat, fresh, frozen and canned fish, canned vegetables, confectionery products, are the leading industries of Seattle. Of the total manufactured products produced in Seattle in 1914, as given by the United States Census report, 38% were food products. The statistics prepared by the Bureau of Industrial Research show that between 35% and 40% of the total production of manufactured goods are food products.

Baking Powder, Coffee, Extracts, etc.—These products are manufactured by firms doing an exclusive business in one or a number of these products, or as incidental to the wholesale grocery business. The market territory covered is Washington, Idaho, Oregon, Montana and Alaska. One firm covers the larger part of the United States and Canada, with some foreign business. The raw materials are bought in Eastern jobbing centers, and directly from the producing sections of the world.

Bakery Products—There are 37 bakeries operating in the city which do an exclusive wholesale or a wholesale and retail business. If the shops doing only a retail business were included, the total would be at least equal to the number given by the United States Census report of 1914—namely, 132.

The amount of factory bakery goods consumed in Seattle per capita is not equal to the consumption in other Coast cities. This is believed by experienced men to be due to the lack of advertised brands. A very serious handicap to the bakeries is the present high prices of raw materials, and this has forced several of the smaller wholesalers to quit their wholesale business and cater only to a local retail trade. Another problem in the cost of production is a wasteful delivery system, as several bakeries often cover the same territory. Effort is being made to meet these problems through increased efficiency in production. Within the last year two firms have built new bakeries, and another firm has remodeled its shop to embody the most modern methods of production. Two firms engaged in the making of hard-tack and toast find a ready market for their output through jobbers in the Northwest, Alaska, British Columbia and Hawaii.

There are at present two cracker factories, and these utilize Washington and Alaska as their markets.

Butter—The production of butter has increased enormously in the last two years, between 40% and 45% in value, and an increase

of six factories. The output is sold in Western Washington and Alaska. The production of Seattle creameries comes far from supplying the demands of the markets drawing upon her. To supply these demands a large part of the production of creameries in the state are jobbed in Seattle. The cream for Seattle creameries is shipped here from Western and Eastern Washington and part of Oregon.

Confectionery Products—Confectionery products manufactured in Seattle are sold in Washington, Idaho, Oregon and Alaska. Some foreign business with Australia and the Orient is transacted. Only the larger firms are able to avail themselves of the larger markets. The raw materials are bought from producing centers or through local dealers.

Fisheries—The fisheries which are located in Seattle, like the other large fisheries of the Northwest and Alaska, place their products all over the world. The fish are caught along the North Pacific coast of North America.

Flour and Cereal Millers—Seattle is the flour center of the Northwest, both in manufacturing and jobbing, as borne out by all available statistics. Besides the lucrative domestic business of the United States, a large foreign market in the Orient and South America is covered. The supply of wheat is drawn largely from the Northwest. Grains for making ground feed are bought from the Middle West, Manchuria and Japan.

Fruit and Vegetable Canneries—While much fruit is canned in the State of Washington, only two canneries are located in Seattle. The markets for canned products are the middle west and southern part of the United States. Fruits and vegetables from Puget Sound and Eastern Washington are used for canning.

Meat Packers—Meat packing was the leading industry for the city for the past several years. Due to the phenomenal activity in shipbuilding, it will take second place in 1917. The market territory is Western United States and Alaska, with some use of the Oriental market. During the past year Eastern United States and Europe drew upon Seattle for meat products to some extent to satisfy war demands.

Miscellaneous—Most of the other food products are marketed locally. However, some lines, such as macaroni, pickles and preserves, are marketed in the Northwest and Alaska. One manufacturer of salad dressings and canned puddings supplies the Pacific Coast and

Hawaii with its products. During the past year two firms manufacturing preserves and pickles have been forced to quit on account of shortage of raw materials.

General—One of the demands of the food industries is a larger production of raw materials. This is at present a national cry because of the large demands for war supplies. Even under ordinary conditions the supply does not seem to be equal to the demand. It was generally expressed by manufacturers of this class that every effort possible be devoted to interest the farmers in the increased production of more hogs, cattle, grain, vegetables, etc.

TABLE V—IRON AND STEEL

	No. of Firms	Reporting Firms	Persons engaged in the Industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	P.C. Consumed in Seattle and King County	Reporting Firms	Capital Invested	POWER				FUEL		Cost of Power and Fuel	
												Report. Firms	Electricity H.P.	Report. Firms	Steam H.P.	Both Steam & Electric H.P.	Report. Firms		Report. Firms
All Iron and Steel Products	131	96	2,337	74	\$3,039,592	86	\$6,709,747	..	.....	87	\$2,830,830	87	3,337	1	180	3	705	..	\$82,693
Boiler and Sheet Iron Products	8	6	147	6	158,821	6	327,864	6	86	6	147,000	6	417	..	..	..	..	6	4,404
Electric Machine Shop Products	7	7	182	7	243,400	7	615,000	7	25-30	6	215,000	6	157.5	..	..	..	..	1	1,227
Forge Products	6	6	110	6	186,400	6	461,200	..	..	6	180,000	3	90.5	..	..	..	..	5	11,312
Partial Reports	3	3	85	..	..	1	10,000	..	..	3	81,000	2	25	..	180	2	355	..	2,700
Totals	11	9	195	6	186,400	7	471,200	5	66 2-3	9	261,000	5	115.5	1	180	2	355	1	14,012
Foundry Products—Grey Iron and Steel	13	12	466	12	836,520	12	1,591,700	10	26	12	984,000	12	985.5	..	..	..	..	10	30,351
Machine Shops	33	33	994	33	1,235,051	33	2,989,003	..	..	32	711,312	32	894.5	..	..	1	350	9	26,674
Partial Reports	15	15	129	..	..	9	49,600	..	..	10	85,000	14	116.5	..	..	..	..	2	731
Totals	65	48	1,123	33	1,235,051	42	3,038,603	28	46	42	796,312	46	1,011	..	..	1	350	11	27,405
Ornamental Iron & Wire & Elevators	7	63	7	79,400	7	180,380	..	..	..	7	70,518	7	75	..	..	..	..	3	1,209
Partial Reports	1	3	..	..	1	2,000	..	..	..	1	2,000	..	..	..	..	..	..	1	135
Totals	15	8	66	7	79,400	8	182,380	7	90	8	72,518	8	80	..	..	..	..	4	1,444
Miscellaneous	3	120	3	300,000	3	473,000	..	..	..	3	350,000	3	420	..	..	..	..	1	3,850
Partial Reports	3	38	..	..	..	1	10,000	..	..	1	5,000	1	150	..	..	..	..	..	..
Totals	12	6	158	3	300,000	4	483,000	..	..	4	355,000	4	570	..	..	..	..	..	3,850

IRON AND STEEL

Up to the war period, Seattle had not made much progress in iron and steel products, but since then all shops have been operating at capacity, and there has been considerable increase in number and variety of factories.

A majority of the machine shops, foundries and forge shops are custom. However, several turn out a stock line of sawmill machinery, mining machinery, can-making and canning machinery and engines. The shipbuilding industry has created a demand for all kinds of iron and steel products, either directly or indirectly, with the result that considerable expansion has occurred. Many of the plants have increased their size to meet these growing demands, and others have been established to take care of entirely new wants.

Shop catering to custom work depends on the local markets, but in the case of shops turning out a special product the markets are larger and take in the entire Northwest. Some lines of products, as stoves, sawmill machinery, must meet eastern competition. At present this seems to be done with success, as attested by the large increased output during the last two years. Shops manufacturing lines of patent specialties market their products all over the United States, and one company manufacturing electrical wireless equipment at present has a worldwide trade.

The big difficulty facing local manufacturers of iron and steel products is the source of supply of raw material. However, this promises to be taken care of satisfactorily in the future.*

The markets on the Coast as yet for many lines of iron and steel products are too small to permit the local manufacturers to compete successfully with the large scale production of eastern centers. Where the market is sufficiently large to warrant local production on a small scale, the advantage of being in the market, other things being equal, makes successful competition with eastern manufacturers possible.

* Bulletin 2, "Iron Ore Resources of the Pacific Northwest," Bureau of Industrial Research.

TABLE VI—LEATHER

	No. of Firms	Reporting Firms	Persons engaged in the industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	P. C. consumed in Seattle & King Co.	Reporting Firms	Capital Invested	Reporting Firms	Quantity	POWER				Reporting Firms	FUEL		Cost of Power and Fuel
														Report. Firms	Electric. H. P.	Report. Firms	Both Steam & Electric. H. P.				
All Leather Products	26	20	408	17	\$1,452,492	20	\$2,212,398	19	...	19	\$848,600	...	...	17,224	2	262	...	...	...	...	\$6,053
Belting	33	17	117	3	107,500	3	161,000	2	46	2	31,000	...	...	2	12	...	...	...	1 Gas, Wood	...	114
Shoes	13	193	193	5	567,765	5	814,360	5	...	5	400,600	5	255,938*	5	167	...	...	...	2 Coal, Gas	...	2,342
Miscellaneous	11	8	113	8	268,476	8	480,167	8	77	8	262,000	...	...	8	41.5	...	...	...	2 Gas, Wood	...	86.5
Hide Tanneries	33	...	...	...	...	...	...	...	...	...	...	...	...	2	3	...	...	...	...	...	...
Wool Pulling	13	4	83	2	\$508,750	4	\$756,871	3	34	4	\$155,000	...	...	...	...	2	262	3 Coal, Oil, Gas	...	...	2,732
Leather Gloves	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Totals	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

* Pairs.

LEATHER AND REMANUFACTURED GOODS

Leather products that are made here largely supply local demands, and in some instances the demands of the Northwest. Of the seven shoe factories one turns out high grade ladies' and men's shoes which are sold in the Northwest, on the Pacific Coast and in South America and the Orient. The companies which pull wool buy their pelts in Western United States and Australia and market their product in the United States and Europe.

Leather gloves, leather belting and leather novelties made here are sold in all the Northwestern states and Alaska.

Leather has to be bought either in the East or California. It seems as though a great advantage would accrue to local manufacturers if the hides from the Seattle meat packers could be tanned in Seattle, rather than being sent out, and then sent back as leather to be made into a finished product.

TABLE VII—SOFT DRINKS AND BEVERAGES

	No. of Firms			Reporting Firms	Value of Raw Material	Reporting Firms	Value of finished Products	Reporting Firms	Capital Invested	PR		FUEL	
		Reporting Firms	Persons engaged in the Industry							Report. Firms	Electric, H.P.	Report. Firms	Cost of Power and Fuel
Beverages.	14	10	66	3	\$63,200	6	\$234,264	9	\$178,900	8	72	4	Oil-Gas \$5,157

BEVERAGES

The manufacture of soft drinks is largely an industry catering to local demands. Since the state has been dry the output of the factories already in the field has decreased and competition has been intensified by new firms, with the result that some companies have been forced to quit.

Two breweries out of four have adjusted themselves to the change and are now manufacturing non-alcoholic beverages from grains and fruits. Their products are marketed in Washington, Oregon and Alaska.

TABLE VIII—LUMBER AND ITS REMANUFACTURES

	No. of Firms	Reporting Firms	Persons engaged in the Industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	P.C. consumed in Seattle and King County	Reporting Firms	Capital Invested	Reporting Firms	Quantity	POWER				FUEL		Cost of Power and Fuel	
														Report. Firms	Electricity H.P.	Report. Firms	Steam H.P.	Report. Firms	Steam & Elec. Both H.P.		Report. Firms	Report. Firms
All Lumber Products																					
excluding Out of City Factories...	35	77	2,482	65	\$3,295,578	77	\$7,851,658	...	...	...	71	\$4,475,427	...	...	565,038	13	4,630	2	1,165	...	\$59,439
Cabinet Shops...	19	118	19	19	105,313	19	273,364	...	...	...	17	87,200	...	...	18	235.5	...	...	1	...	3,068
Partial Reports...	1	1	1	1	4,137	1	4,137	...	...	...	1	1,200	...	...	5	...	...	...	...	...	...
Totals...	24	20	119	19	105,313	20	277,501	20	90	...	18	88,400	...	...	19	240.5	...	...	1	...	3,068
Furniture...	5	5	161	5	394,000	5	660,000	...	...	...	4	276,000	...	...	4	287.5	...	...	165	...	12,840
Partial Reports...	9	112	166	5	394,000	7	13,500	...	...	...	2	4,500	...	...	2	3.6	...	...	1	...	12,840
Totals...	6	7	166	5	394,000	7	673,500	7	59	...	6	280,500	...	...	6	291	...	...	1	...	12,888
Lumber Mills (inside City)...	...	6	720	6	1,177,000	6	2,105,000	...	...	...	1	1,347,000	...	...	2	2,200	5	3,150	1	1,000	8,000
Partial Reports...	...	4	705	...	...	4	1,994,000	...	...	...	3	425,000	...	...	8	175,331,621	...	...	...	...	...
Totals...	14	10	1,425	6	1,177,000	10	4,099,000	10	32	...	8	1,772,000	...	...	8	175,331,621	...	...	...	...	...
Sash and Doors...	...	11	245	11	314,306	11	668,649	...	...	...	11	458,677	...	...	111,225	...	...	...	...	...	10,221
Partial Reports...	3	3	36	...	...	3	46,100	...	...	...	3	44,000	...	...	3	50	...	...	...	...	1,950
Totals...	14	14	271	11	314,306	14	714,759	14	78	...	14	502,677	...	...	141,275	...	...	...	...	...	12,171
Shingle Mills...	9	8	237	8	318,481	8	558,426	...	...	...	8	371,350	...	...	243,492,060	5	825	...	...	...	1,045
Pattern Shops...	7	4	11	4	3,650	4	22,900	4	100	...	3	8,600	...	...	Shingles	...	...	...	...	...	360
Woodenware, Lumber Remanufactures...	...	6	93	7	178,500	7	304,400	...	...	...	7	261,900	...	...	...	...	...	...	...	...	2,585
Partial Reports...	2	2	11	...	...	1	50,000	...	...	...	1	25,000	...	...	...	...	1	60	...	...	...
Totals...	12	8	104	7	178,500	8	354,400	...	...	...	8	286,900	...	...	...	...	...	...	...	...	...
Factribit Houses...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Wooden Pipe...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Cresosoted Lumber...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Totals...	6	6	149	5	804,328	6	1,151,172	...	...	...	6	1,165,000	...	...	...	...	...	...	...	...	...
Lumber Mills (outside City)...	...	4	995	4	1,015,000	4	1,490,250	...	...	...	5	3,797,000	...	...	...	...	...	...	...	...	...
Partial Reports...	2	2	800	...	...	2	1,195,000	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Totals...	16	6	1,795	4	1,015,000	6	2,685,250	6	2—	...	5	3,797,000	...	...	...	...	...	...	...	...	19,322

* Balance no report or use waste. ** Generates electricity.

LUMBER AND MANUFACTURERS

Lumbering is the leading industry of the Northwest. It was the first industry utilizing one of the great natural resources of the Northwest, and consequently was the first thing to attract the attention of the rest of the United States.

Lumbering is an industry which keeps near to its source of supply, and as a result the number of mills in Seattle have been decreasing as the pioneer days have passed.

The last year for the lumber industry has been one in which it can be well said that it marked time. The mills located in Seattle supply the local market, about 30% to 35% of their output going for this purpose. The balance of the output is sold in the lumber markets of the world. Sixteen mills located in adjoining counties to King have head offices in Seattle. Practically all of their output is sold in the large lumber markets of the United States and foreign countries.

The large output of creosoted lumber of the two creosoting plants of Seattle is sold in the Pacific Coast states. Creosoted paving blocks have a much larger distribution, which extends to the Orient and a large part of the United States.

The lumber remanufacturers depending upon the local building trade have just been able to hold their own during the last few years, as was true of all lines depending on building activity. The cabinet shops in Seattle are largely custom shops, only a few turning out a line of showcases or refrigerators. The competition in this line comes from Portland, where there are several shops which have put the production of showcases, etc., on the basis of modern factory production. Four of the larger shops do fixture work for the Northwest and Alaska; the other shops cater to a local trade. Some complaint was made that local men patronize outside manufacturers in Portland and Puget Sound cities.

Sash and door manufacturers of Seattle have had to contend with the general period of depression in building for the past several years. Five factories reported a business in the Northwestern states. Alaska and the Philippines and Hawaii. Recently some shipments have been made to eastern markets to meet the large war demands. The large and more modern factory methods employed by the sash and door factories in other Puget Sound cities enables them to take a much larger advantage of the more extensive markets than the local manufacturers.

Local furniture manufacturers have had to contend with com-

petition from Portland and eastern manufacturers, and the fact that local retailers seem to prefer eastern goods to the local goods. This may be due to a difference of quality and costs, but it is felt by the local manufacturers to be due to prejudice against local-made goods. At least a larger patronage of local-made products would greatly increase the output of the present factories. Wooden pipe made in Seattle is sold all over North America, in Hawaii and Japan.

Factory-built and lumber-cut buildings depend on the trade of the Northwest and Alaska, due to the fact that freight rates will not permit them to compete with eastern manufacturers in eastern territories.

The different lines of woodenware manufactured here are sold in the Northwest and Alaska. It seems that Seattle, with its large lumbering interest, offer large opportunities for development in woodenware lines. Some complaint was found against the high prices which must be paid local jobbers for hardware accessories, and in some instance it appears this is working a detriment to the industry.

METAL PRODUCTS OTHER THAN IRON AND STEEL

The brass, bronze and aluminum foundries do largely a local custom trade. Four plants turn out special lines of products of builders' and plumbers' hardware and ship chandlery. The brass, bronze and aluminum industry at present is centralized in Connecticut. It appears that Seattle's nearness to the source of supply of the raw materials and the recent increased demand for certain lines of finished brass and bronze goods, as marine hardware and rolled copper, ought to soon see the establishment of this industry here on a large scale in competition with the eastern centers.

Sheet metal shops cater entirely to custom works, and that work is largely dependent upon the building activity. This has decreased the amount of business in this industry since the Government Census of 1914. However, an adjustment is taking place in some instances through the demand of certain kinds of sheet metal products for the shipbuilding industry. The production of the tin can factories has been growing steadily, and last year has seen the establishment of a branch factory of the American Can Company in Seattle. A large percentage, however, of the tin cans used in this territory are manufactured by the firms using them.

Nothing in the way of a special line of manufactured sheet metal products as put out by eastern manufacturers can be looked for in Seattle until the tinplate industry is established in the Northwest, so it would seem. While Seattle is near to the mines of tin ore in the East Indies, Bolivia and the recently developed mines of Alaska, and large amounts of tin ore pass through her port to eastern manufacturing centers, and then back again as tinplate to be used here, the lack of a developed iron and steel industry in this territory has prevented the manufacture of tinplate here.

TABLE IX—METAL PRODUCTS, OTHER THAN IRON AND STEEL

	No. of Firms	Reporting Firms	Persons engaged in the industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	P.C. consumed in Seattle and King County	Reporting Firms	Capital Invested	P.W.R.		Reporting Firms	FUEL	Cost of Power and Fuel
												Electricity	H.P.			
All Metal Products other than Iron and Steel.....	89	66	667	47	\$671,061	55	\$1,649,664	..	..	55	\$847,300	35	730	..	..	\$10,088
Brass, Bronze, Aluminum, Foundry Products	..	6	67	6	..	..	309,139	..	..	..	..	..	..	..	..	..
Partial Reports	..	3	14	..	..	6	10,000	..	..	..	106,500	6	73	4	Gas, Oil	4,116
Totals	9	9	81	6	..	7	319,139	7	67	7	131,500	7	80.5	..	..	150
Lighting Fixtures	..	3	56	3	74,000	3	177,000	..	..	3	143,000	3	37.5	1	Gas	862
Partial Reports	..	2	4	..	..	..	..	..	..	..	..	1	2	..	..	..
Totals	8	5	60	3	74,000	3	177,000	..	..	3	143,000	4	39.5	1	Gas	862
Oxy-Acetylene Welding	6	4	16	3	4,167	4	41,726	3	87	4	11,550	3	9	..	..	840
Sheet Metal Shops, including Roofing and Furnace Work...	..	23	142	23	237,423	23	464,426	..	..	21	117,300	6	42.5	10	Gas, Charcoal..	852
Partial Reports	..	8	47	..	..	5	100,950	..	..	7	61,950	..	..	..	..	..
Totals	43	31	189	23	237,423	28	575,376	17	91	28	179,250	..	..	..	..	..
Sheet Metal—Auto	4	4	23	4	6,840	4	42,500	4	90	4	9,200	4	14	3	Gas	602
Coppersmithing	2	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Electro-Plating	3	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Tin Cans	3	1	146	..	..	..	..	..	..	..	..	..	..	..	..	..
Miscellaneous	11	5	146	5	165,681	5	440,330	..	all	5	352,500	3	..	..	..	..
Partial Reports	..	4	35	..	..	..	..	..	..	..	..	..	..	..	..	..
Totals	19	13	198	8	170,631	9	493,923	..	..	9	372,800	11	544	..	..	2,666

PRINTING AND PUBLISHING

In obtaining figures for statistics on this industry no effort was made to secure data by enumerators, except for the three daily newspapers. Publishers were circularized by mail with a questionnaire, but none answered. If the figures for publishers were included, it is likely that there would be an increase over the number of shops reported by the United States Census for 1914. It is believed that the number of employees and the value of the production would also show increases.

The printing done in Seattle is almost entirely for the local trade. Some of the allied industries, as engravers, electrotypers, calendar printers, do work for the Pacific Coast and the Northwest. Two firms are engaged in show printing, and they serve the Western part of the United States.

The stock used in printing has to be brought from various producing stations of the United States or from the local dealers.

The eastern printing firms have local representatives in the Seattle territory, and large amounts of printing go to these firms every year. In addition to this, local competition is very keen, and considerable price-cutting is done. Sixteen firms, among them some of the largest printers, indicated the need of home consumption and the education of printers to the need of cost accounts, so that an intelligent value for a job of printing could be established.

TABLE X—PRINTING AND PUBLISHING

	No. of Firms	Reporting Firms	Persons engaged in the industry	Reporting Firms	Value of Raw Materials	Reporting Firms	Value of Finished Products	Reporting Firms	P.C. consumed in Seattle and King County	Reporting Firms	Capital Invested	P.W.R.		FUEL		Cost of Power and Fuel
												Report. Firms	Electricity H.P.	Report. Firms	Coal, Gas	
All Printing and Allied Products	134	102	1,425	91	\$1,108,134	102	\$3,531,664	101	.....	101	\$1,391,440	96	761	.....	.....	\$23,398
Printing	60	539	61	412,238	61	1,294,147	.....	60	.....	60	752,140	59	409	.....	6 Coal, Gas	7,393
Partial Reports	11	91	3	1,889	11	154,189	.....	12	.....	12	80,800	9	28	.....	.....	182
Totals	98	71	630	64	417,127	72	1,448,336	65	92	72	832,940	68	437	.....	.....	7,575
Book Binding	8	5	22	5	7,050	5	34,500	5	91	5	27,500	5	6	.....	1 Coal	297
Engravers—Photo & Cop- per Plate	.....	8	69	8	36,457	8	154,750	.....	.....	8	75,000	8	83.75	.....	5 Coal, Gas	1,372
Partial Reports	1	6	.....	.....	.....	.....	16,000	.....	.....	1	4,000	.....	.....	.....	.....	.....
Totals	*9	9	75	8	36,457	9	170,750	8	92	9	79,000	.....	.....	.....	.....	.....
Lithotyping	.....	5	40	5	Labor	5	80,000	5	97	5	69,000	4	4.75	.....	5 Coal, Gas	1,587
Paper Boxes, Folding and Stiff	.....	3	77	3	60,000	3	134,333	.....	.....	3	63,000	3	45.75	.....	.....	942
Partial Reports	1	50	.....	.....	.....	2	136,000	.....	.....	1	5,000	.....	20	.....	.....	100
Total	*6	5	127	3	60,000	5	270,333	4	80	4	68,000	5	65.75	.....	.....	1,042
Calendars	1	.....	.....	.....	.....	.....	.....	1	20	.....	.....	.....	.....	.....	.....	.....
Lithography	*2	.....	.....	.....	.....	.....	.....	2	60	.....	.....	.....	.....	.....	.....	.....
Newspapers	*3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Show Printing	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Miscellaneous	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Totals	7	.....	531	6	587,500	6	1,527,745	1	25-30	6	315,000	6	163.5	.....	2 Oil, Gas	11,525

* These do not duplicate firms in printing.

TABLE XI—SHIPBUILDING

	No. of Firms	Reporting Firms	Persons engaged in the Industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	Capital Invested	Reporting Firms	Quantity
Ship Building—Steel, Wood, Drydocking and Boatbuilding ..	29	20	3,995	16	\$363,091	17	\$14,784,915	16	\$ 734,450	..	.....
Ships—Steel. Capacity 1917..	4	4	9,200	..	..	..	9,500,000	..	4,000,000	4	95,000*
Ships—Wooden. Operated 1916..	9	4	1,550	..	..	..	9,500,000	..	4,000,000	4	340,000*
Ships—Wooden & Steel. Proposed operating 1917.	7	3	1,200	..	..	..	..	..	1,250,000	6	114,000*

* DWT. ** April.

SHIPBUILDING

The shipbuilding industry belongs to that class of industries characterized in the popular vernacular of the day as a "war baby." During the compilation of this report it has continued to grow, and the data which is presented comes far from telling the story of the day. A comparison, however, which calls attention to the wonderful strides of the industry in the United States and what it means to Seattle is the fact that at the present time Seattle employs one-fourth as many men as the shipbuilding industry of the United States did in 1909. Another comparison to which previous attention has been called is the fact that the building of ships in the Puget Sound territory is as large an industry as the lumbering industry for the entire state of Washington.

The establishment of a shipbuilding industry in the Northwest has called into existence subsidiary factories for forgings, galvanizing, castings, of iron, steel, brass and bronze, and for machine work. If this industry is able to be put on a permanent basis, and ships can be built after the war, it will mean the growth of the industrial life of Seattle in the form of more "grouped" industries to take care of its needs and more "market" industries to supply the increased population. In which case it can well be said shipbuilding was the beginning of things in the production of Seattle-made goods.

How rapid the growth has been is evident from the fact that in two years it grew from nothing to an annual production of over \$70,000,000.

STONE AND CLAY PRODUCTS

The markets of brick and tile are local, wherever manufactured. The only chance to develop a larger market is in the fire-clay products. At present only one company manufactures fire-clay brick from the extensive clay deposits, and consequently large amounts of fire bricks are shipped into this territory.

Terra-cotta products manufactured by two companies are marketed in the Northwest, Alaska and British Columbia.

Cement consumption is practically entirely in Washington. However, a small amount is consumed by Alaska.

Plaster and plaster products are marketed in Western United States. One company recently located in Seattle contemplated selling bisque dolls all over the United States.

Marble and granite quarried in Washington and Alaska find a limited market in Washington, Oregon and Idaho through the marketing efforts of four local manufacturers. Large amounts of Vermont marble and other eastern marble are used in the Northwest in preference to the local product.

Glass products produced in Seattle consist entirely of leaded art glass and various other kinds of finishings. The production is dependent upon local consumption. However, one firm within the last year has entered the Oriental market both as a jobber and manufacturer.

TABLE XIII—TEXTILES

	No. of Firms		Persons engaged in the industry		Reporting Firms		Value of Raw Material		Reporting Firms		Value of Finished Products		Reporting Firms		P.C. consumed in Seattle and King County		Reporting Firms		Capital Invested		Reporting Firms		P.W.R.		FUEL		Cost of Power and Fuel
	No. of Firms	Persons engaged in the industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	P.C. consumed in Seattle and King County	Reporting Firms	Capital Invested	Reporting Firms	Electricity H.P.	Reporting Firms	FUEL	Cost of Power and Fuel												
All Textile Products	64	53	1,422	41	\$1,645,356	48	\$3,398,302	..	..	49	\$1,067,390	47	386	..	\$10,944												
Awnings, Tents, Sails, Rigging	9	7	90	7	593,110	8	1,063,774	8	38	8	117,000	7	26	..	335												
Caps and Hats	7	5	134	3	8,600	5	178,000	3	30	4	70,000	3	13	2	722												
								all						Gas													
Cloaks and Suits	5	5	77	4	135,092	5	278,023	5	60	5	71,000	5	8.5	..	207												
Carpets and Rug Weaving	..	..	15	3	1,900	3	13,785	..	..	3	3,800	2	14	..	402												
Partial Reports	..	..	22	..	..	1	30,000	..	..	3	41,800	2	22.5	1	450												
Totals	7	6	37	3	1,900	4	43,785	3	90	6	45,600	4	36.5	..	852												
Hats—Ladies	1	1	89	2	27,050	3	77,881	3	47	3	127,000	4	10.5	1	650												
Knitted Goods	1	1	127	7	102,383	7	225,724	..	72	7	137,000	7	21	1	620												
Men's Clothing, including Shirts	5	5	459	3	440,000	3	897,000	..	..	4	309,790	5	66	..	933												
Neckwear—Ladies' and Men's, including Ladies' Silk Shirt-waists	3	3	36	3	61,500	3	107,000	..	42	2	25,500	3	5	..	224												
Garments—Ladies' and Children's	4	4	150	3	60,000	4	210,000	4	60	3	44,000	4	16.5	..	350												
Miscellaneous	13	7	223	6	215,721	6	316,615	..	..	7	120,500	5	183	4	6,051												
														Coal, Wood..													

1 Hats. 2 Caps.

TEXTILES

The textile industry as it is established in Seattle is founded here primarily because it is in the market for its finished product. Awnings, tents, sails and riggings are sold nearly entirely in the local market. A small percentage is sold in other Coast cities and Alaska. Cloaks, garments, caps and men's working clothes are sold in Alaska and in the Northwest.

The supply of raw materials is brought from the eastern and southern textile centers. The statistics for 1916 show a large increase in the value of production of every line of textile products in a two-year period, and nearly every firm contemplates increased production for 1917. However, some sentiment was expressed that more home-made clothing should be bought by the local trade.

There is one woolen mill in the industrial territory of Seattle which markets its production locally and on the Pacific Coast.

TABLE XIV—TOBACCO MANUFACTURERS

	No. of Firms	Reporting Firms	Persons engaged in the Industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	in Seattle and King County P.C. consumed	Reporting Firms	Capital Invested	Reporting Firms	Quantity
Cigars	7	5	65	4	\$59,000	4	\$114,200	5	40	5	\$42,100	5	2,435,000*

* Cigars.

CIGAR MANUFACTURERS

In 1914 Seattle had 24 cigar factories. The list has dwindled to seven plants, four of which employ practically all the people engaged in this industry. The other three shops employ one or two men each.

The large decrease is attributed to the fact that before the state went dry the output of the factories was sold to the saloon trade. Only those shops which have built a local trade with the retail cigar stores by local advertising have been able to continue in competition with nationally advertised brands.

The climatic conditions in the Puget Sound region are ideal for the manufacture of cigars, and it appears that the market territory is large enough to support a large production. But it seems local goods cannot compete with established advertised brands of large eastern manufacturers. San Francisco has one cigar factory employing between 200 to 300 people, and the output is easily sold, as the civic pride of Californians prompts them to buy home products in preference to others.

TABLE XV—VEHICLES AND PARTS

	No. of Firms	Reporting Firms	Persons engaged in the industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	P.C. consumed in Seattle and King County	Reporting Firms	Capital Invested	Reporting Firms	Electricity H.P.	Report. Firms	FUEL	Cost of Power and Fuel
All Vehicles and Parts Builders	24	22	450	14	\$229,175	16	\$5,944,437	15	..	..	\$798,500	18	331	..	..	\$10,296
Auto Body Builders	4	4	80	4	60,500	4	220,000	4	80	4	147,000	4	80	2	Gas, Coal	2,876
Truck Attachments and Motor Trucks	4	4	77	2	183,750	3	459,500	3	65	2	85,000	3	71	..	..	920
Wagons and Carriages	9	7	27	6	22,542	6	61,000	6	95	6	42,500	7	55	6	Coal	1,772
Builders and Repairers	2	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Auto Builders and Assemblers	2	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Auto Tops, Cushions, etc.	2	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Auto Spring Manufacturers	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Totals	41	41	266	2	23,383	3	5,203,937	3	..	3	524,000	4	125	3	Coke, C'l, W.	4,728

VEHICLES AND PARTS

Wagon and carriage shops are gradually dropping out, or adjusting themselves to the new order of things by putting in equipment to build commercial auto bodies. The work in either case is custom, and depends upon local markets.

The auto body, top and curtain shops do only repair or custom work. They are in a very prosperous condition. Work is done not only for local territory, but also for Alaska and the back territory of Washington.

There are two firms who have perfected automobiles and are at present trying to put their product on the market. No local capital has been available for their development, and consequently very little has been accomplished.

One firm manufactures a motor truck which is sold in all parts of the state.

There are three firms engaged in the manufacture of truck attachments, which find a very ready market in the Northwest and Alaska. One of these three firms has established a branch factory in Cleveland, Ohio.

TABLE XVI—MISCELLANEOUS

	No. of Firms	Reporting Firms	Persons engaged in the Industry	Reporting Firms	Value of Raw Material	Reporting Firms	Value of Finished Products	Reporting Firms	P.C. consumed in Seattle and King County	Reporting Firms	Capital Invested	Reporting Firms	Quantity	POWER				FUEL		Cost of Power and Fuel
														Report. Firms	H.P.	Report. Firms	Steam H.P.	Report. Firms	Report. Firms	
All Miscellaneous Products	118	55	498	34	\$280,077	52	\$1,733,188	..	.....	50	\$1,353,542	..	.....	36	508	2	390	..	.....	\$22,044
Artificial Limbs & Appliances.....	3	3	16	3	9,250	3	28,000	3	40	3	24,000	..	.....	2	10.5	..	..	3	Gas	214
Asbestos Goods.....	3	3	95	3	31,000	3	624,000	2	60	3	218,817	..	.....	3	13	..	..	2	Coal	318
Ice.....	3	3	38	2	5,300	3	144,000	..	all	3	450,000	3	44,200	1	320	2	390	3	Coal, Wood..	19,200
Brooms & Brushes	4	3	18	1	55,000	4	210,000	..	..	4	118,500	..	.....	4	90	..	..	1	Gas	240
Barriers and Fur Tanners.....	11	11	61	4	33,050	11	153,000	..	..	10	218,500	..	.....	11	15.5	..	..	1	..	432
Opticians—Mfrs....	6	5	56	4	57,477	5	222,388	5	57	5	100,000	..	.....	5	16.5	..	..	1	Gas	612
Picture Framing..	6	5	22	4	21,800	5	61,500	..	..	5	53,250	..	.....	1	2.5	..	..	1	Gas	30
Stamps & Stencils.	6	3	26	3	12,200	3	72,000	3	47	3	24,175	..	.....	3	29	..	..	2	Coal, Gas..	700
Trunks.....	3	3	28	3	23,000	3	60,000	2	85	3	38,000	2	8,500	1	2	..	..	..	..	100
Taxidermists.....	3	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Violin Makers.....	3	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Window Shade Mfrs.....	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Jewelries—Mfrs....	11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Miscellaneous.....	21	14	78	7	32,000	12	158,300	..	..	11	108,300	..	.....	5	9	..	..	2	Gas	198
Totals.....	40	14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
New and Unclassified.....	29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Tons.

MISCELLANEOUS

Classified under the head of miscellaneous industries are manufactured products such as costumes, fur goods, ice, picture frames, stamps and stencils, window shades, etc. All of the above products depend almost entirely upon the trade of the city or the nearby surrounding towns. Besides the above mentioned products, others are manufactured by costume shops for the local trade.

Asbestos goods manufactured in Seattle are sold in all the Northwestern states. Brooms are made by four companies, and they market their products through local jobbers in Washington, Oregon and Idaho. One firm makes a very high grade line of paint, floor and household brushes, which find a ready demand in the Northwest and in the Pacific Coast states.

Of more than special interest is the fact that Seattle has the largest jewelry factory west of Chicago. There is one shop manufacturing an exclusive line of ivory products sold in all parts of the United States.

Optical goods are finished for the consumer by six local firms. One of these does an exclusive business in Washington, Oregon, Idaho and Alaska. Hair goods made in Seattle are sold in the Western states. The only hotel register made west of Chicago is manufactured in Seattle, and is sold on the publicity plan in all the states west of the Mississippi.

One coal company manufactures briquettes, which go to supply the large demand for this product in Washington, Oregon, Idaho and Alaska. This company also produces pulverized coal. The production of this product from the coal resources of Washington will in time become a big industry here, as the consumption of fuel oil is replaced by pulverized coal. The replacement of oil burners by pulverized coal burners has been successfully accomplished in eastern manufacturing centers.

Chapter IV

UNCLASSIFIED INDUSTRIAL OPPORTUNITIES*

Very many suggestions were made by manufacturers relative to new factories for the production of articles with which they were concerned. Some of these suggestions have been enumerated under the classification given on page —. The reader will, however, be interested in certain phases which will be briefly discussed at this point.

TANNERIES AND TANNIN EXTRACT MANUFACTURE

Eight leather manufacturers agree in the need of a tannery to supply the kinds of leather required for their respective needs. They say the hides are here. From research¹ carried on in the laboratories of the University of Washington we know that the Pacific Northwest is rich in bark suitable for tannin production. The western hemlock, Douglas fir, western larch and western yellow pine barks all yield extract of proper quality and in sufficient quantity to warrant the manufacture of tannin extract. When it is realized that in normal times 50% of our extract is imported, additional cause exists for the plausibility of a tannin extract industry. The production of tannin extract in territory convenient to Seattle could advantageously be carried on in connection with pulp mills. These use hemlock bark, and the latter is in reality a by-product used as fuel or destroyed in order to get rid of it. In reality it is ideal material for tannin production.

WOOD PRODUCTS

The disposal of mill waste is not a serious problem in Seattle, since a good demand exists for it as a domestic fuel. It is questionable whether its use as fuel serves the best economic use. Recently a considerable demand has arisen for charcoal in metallurgical work. During the war a shortage of alcohol, acetone and acetates exists. The demand for tar flotation oils is also fairly large. On this basis, wood distillation would probably be a satisfactory industry.

POTASH

The national shortage of potash has emphasized the need for its production from Pacific Coast kelp and other sources. No beds of

*Additions have been made to this portion of the MSS. by the editors.

¹"Tannin Content of Pacific Coast Trees," J. Ind. Eng. Chem., 7, 915 and 9, 1096.

kelp of sufficient size are near Seattle, although a number of such beds occur in Puget Sound. Research work at the University, however, shows that fir wood ash contains about 7% potash (K_2O). Where wood is used in central heating plants or power stations, provision could be made to collect such ash, and a constant supply could thus be furnished to the adjacent agricultural communities which are now lacking in this fertilizer. While potash from this source would never be a commodity of large dimensions, it would nevertheless be of local importance.

HEAVY CHEMICALS

It is probable that caustic soda and chlorine could be made from concentrated sea water brines in some localities adjacent to Seattle. At the present time a shortage exists for these materials, but in normal times it is questionable whether chlorine could be advantageously marketed on a large scale. This city should always be the center of a series of electro-chemical industries which will eventually be attracted to the Coast on account of the cheap hydro-electric power. Such industries, however, are not likely to be located in the city, but always near the place of power generation so as to avoid transmission costs. The manufacture of nitrite of soda is already an established electro-chemical industry. Potassium chlorate is another local industry of the same type, as is also the electrolytic production of oxygen. The resulting hydrogen from the latter process should be used to hydrogenate fish oils. Calcium carbide should prove feasible, as also the smelting of iron ores to produce steel.

FERTILIZERS

Seattle should look forward to becoming a center for fertilizer materials. Potash and nitrogen products have already been mentioned. Fish waste of the Puget Sound district and Alaska is quite large, and every pound should be conserved. In the Northwest are found 85% of the phosphate deposits of this country. Recent inventions show that phosphoric acid can be cheaply made by electric furnace methods. Hence this industry should eventually center about our larger cities, and Seattle can properly claim its share.

COAL PRODUCTS

Powdered coal firing is rapidly changing our fuel ideas, and emphasizes the importance of our coal deposits. Experimental work in

progress at the University shows interesting possibilities in the distillation of the highly volatile but low grade lignites. In some cases good yields of valuable oils, together with an improved fuel residue, are obtained.

PULP PRODUCTS

Seattle should have a pulp and paper industry. Fiber products, especially insulating conduits, wall board and box board are indicated as being in demand.

FATS AND OILS

War conditions have greatly emphasized the raw materials available to Seattle for soap manufacture and for other oil products. Soya bean oil, copra products, fish oil, etc., are being imported in cargo quantities, and their storage and distribution has been quite a problem. Crushing plants for copra are being contemplated. The same should apply to soya beans. Oil cake and meal as a by-product should furnish a most desirable foodstuff for the dairy and poultry industry of Western Washington. The establishment of oil utilization plants would soon collect various secondary establishments, such as the manufacture of solid fats by hydrogenation, soap, glycerine, rubber substitutes, dairy foodstuffs and fertilizers.

Chapter V.

SUMMARY AND RECOMMENDATIONS

During the preparation of this report, the world war against the Central Powers of Europe, in which the United States has entered, has taken the paramount position in all our activities. The war conditions will prevent much constructive work in the way of assisting established industries or in securing new industries, yet it would seem that much can legitimately be done by taking advantage of the many new opportunities necessitated by the war conditions.

One of the most effective ways of increasing the manufacturing activity of the established firms will be to lessen the existing difficulties to which reference has been made earlier in this report. Lack of consumption of local goods can be overcome partially by having manufacturers place upon their products "Made in Seattle." The desire to buy "Made in Seattle" goods will then depend upon the goods' own merit and the civic pride of the people. The civic pride of the people can be cultivated and increased by advertising and publicity methods. Much effective work has been done in this way by the Seattle Post-Intelligencer's Industrial Page, and the efforts of the Manufacturers' Association and the Chamber of Commerce and Commercial Club.

Lack of capital is generally experienced by the small manufacturing firms. The larger firms are in a better position as a rule to take care of their own financial wants. A feasible plan to overcome this handicap would be the formation of a clearance bureau or an industrial investment corporation. The first plan would require some means whereby manufacturers desiring capital could get in touch with men having capital to invest in local industries. The clearance bureau acts only in the capacity of bringing the two together. Such a bureau would require lists of firms desiring capital and lists of those with available capital to invest. The two then could be brought together thru the services of the clearance bureau.

The chief function of an industrial investment corporation would be to invest in industrial securities or to find a market for them. This plan would impose a great responsibility, and to put it into effect would naturally be a more difficult task than the management of a clearance bureau. Besides this, it would not be as applicable to

Seattle's needs. An industrial investment corporation presupposes a corporate form of business, and as many Seattle firms do not have this form of business, it would not be as useful as a clearance bureau.

The lack of a community interest in manufacturing is being overcome by the reorganized Industrial Bureau of the Chamber of Commerce and Commercial Club, which devotes the larger part of its activities to manufacturing conditions, and the greater activities of the Manufacturers' Association which is devoted exclusively to the manufacturers' interests. It seems that direct contact of representatives of these bodies with the manufacturers can do much to show that their interests are being cared for.

Other difficulties, such as labor troubles, taxes, transportation rates and facilities, are problems which are being met every day by the commercial bodies. The problem here is to be able to reach a larger majority of manufacturers, and impress on existing members what the assistance and services of the commercial bodies means to them in helping to solve these difficulties.

Industrial development today aims largely to meet the national emergency of war conditions; and the task of securing new industries is therefore that of Seattle getting its share of this new development. An example of this development is the recent birth of the shipbuilding industry in the United States and the large increase of this industry in the Northwest. Besides war industries, others not depending on war conditions will increase in size and will seek to locate plants in new territory, and Seattle with a well directed effort should secure a share of this development. In offering advice or assistance to new industries it should be done with much thought and discrimination, so as to avoid failures. A failure is not only bad for the firm which finds itself in that situation, but is a stumbling block to new firms wishing to establish a similar business. Failures generally operate as advertisement against development and will cause industries which by right belong in Seattle to seek other fields.

Under present conditions it seems probable that much can be done towards securing new industries by developing available raw materials. Today, industries are seeking new sources of raw materials and plants are being established at these sources provided manufacturing costs and market conditions are favorable. It seems that a card index of all available raw materials in the Northwest which can be utilized for manufacturing could be made a valuable asset in securing new industries. One plan would be to seek firms to develop these

products, but a more conservative policy would be to have this information in such shape that firms desiring facts of the conditions could easily obtain them. Much effective work has been done by the Los Angeles Chamber of Commerce by this method. An index of available raw materials would include:

1. Minerals and metals, such as copper, iron, tin, etc.
2. Agricultural products, such as grains, wool, hides, etc.
3. Timber products.
4. Trade products passing through Seattle which might be manufactured in Seattle rather than being sent East and then back again.

This is only a tentative list, and it could easily be enlarged. It would also be very desirable to have such data as quantity, cost of obtaining same, owner, market for manufactured product, etc.

Another way of approaching the problem of securing new industries is from the side of manufactured products marketed in the Northwest and Alaska, but manufactured elsewhere. From a long list of such products an investigation of comparative costs of the different products as made locally and by Eastern centers will show whether it can be made in Seattle on a competitive basis. Several industries established here, although in competition with Eastern goods, owe their prosperity principally to the fact that they are located in a larger consuming territory.

By reference to the classification of the industrial growth it is seen that the development of an industry from the raw materials of the community is the same as establishing a "basic" industry. So, also, the developing of an industry depending on the markets of a community is the same as establishing a "grouped" or "market" industry. Both methods could be used very profitably in determining whether there is a field for any certain new industry. In fact, both must be considered in deciding whether an industry can be established profitably in Seattle. But, if one is to be used in preference to the other as a starting point, it will probably be found that the best results can be obtained by using raw materials as a starting point, for in doing so "basic" industry are given birth and a whole field of possibilities is opened up.

The idea of a clearance bureau should be thoroughly worked out; clearance for manufacturing firms wishing to secure capital, and men wishing to invest capital in industries; real estate firms able to pro-

vide for manufacturing firms, and manufacturing firms wishing to secure such sites. The services of such a bureau could also be used in making investigations of whatever nature desired for established firms, or for firms wishing to locate in Seattle. In addition to these services it also should include information files on industries located in the Northwest and possible Northwest industries. The installation of such a bureau would be a valuable benefit for established industries and would operate to secure new industries.

It would be well, also, if a folder or pamphlet were published setting forth the manufacturing conditions in Seattle and its environs and containing a comprehensive discussion of what the commercial bodies are doing to encourage established manufacturers, and what they have to offer in the way of services or assistance to firms wishing to locate in Seattle.

Another thing to which consideration should be given is the collection of all available data on preferential taxes, financial aids and industrial sites as administered in other cities, and a study made as to their adaptability to Seattle and its environs. Much of such information cannot be used to advantage during the present war, but out of such a comparative study as suggested some plan will evolve itself, valuable under present and future conditions.

Lastly, it would seem wise to continue some phase of the work. It, without a doubt, should be now devoted to some particular industry or problem. To quit now and start again at some future time will require that much of what has been done will need to be done over. Further, the Northwest has taken on phenomenal industrial development in many lines in the last fifteen months and much greater activities in every industry await the future. Everything considered, it seems that the times are ripe for such assistance as a continuation of this work would give to the new development.

APPENDIX

FORM OF QUESTIONNAIRE

Confidential

Census of Manufactures

Give data for calendar year 1916, or fiscal year falling mostly largely in 1916.

The following items are to be taken in the form of questions covering the industry in which you are interested, and the replies, where you cannot or do not wish to give exact figures, should be stated in conservative estimates, or averages:

1. Name of concern
2. Official representative
3. Address—Office Phone
 Factory Phone
4. Classification (as iron, brass, shoes, hats, etc.)
5. Detail (special products and brands, if any.)
6. Market territory
7. New market desired: Domestic
 Foreign
8. Kinds of raw material used
 Sources
 Value
9. Annual production: Quantity
 Value
10. Estimated amount of output consumed in Seattle and King County
11. Average number of employees per year
 [Includes executive, clerical, laborers]
12. Amount of capital invested in business
 [Both owned and borrowed]
13. Kinds of power used: Steam, electricity, or gas
 Approximate horsepower
 Cost
14. Kinds of fuel used: Coal, oil, gas or electricity
 Approximate annual consumption
 Cost
15. Articles which in your opinion should be manufactured in or near
 Seattle, and reasons why such articles could be produced here at
 an advantage

16. General sources of trade information used by your firm
[Such as trade journals, Government publications, etc.]
Additional Trade Information Desired
 17. Member of following commercial organizations
 18. Publications issued: Catalogs
Stock lists
 19. Special problems in the solution of which individual or organized
assistance or co-operation is desired
- [If additional space is needed, use back, or separate sheet]

Signed by.....

(Pres.) (V.-Pres.) (Sec.) (Treas.) (Mgr.)

MAIL TO: BUREAU OF INDUSTRIAL RESEARCH,

UNIVERSITY OF WASHINGTON,

BAGLEY HALL

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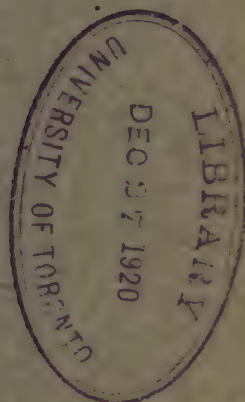
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF WASHINGTON

Eng. Exp. Sta. Series

Bulletin No. 4

A Summary of Mining in the
State of Washington

ARTHUR HOMER FISCHER



SEATTLE
Published by the University
November, 1918

Entered as second class matter, at Seattle, under the Act of
July 16, 1894

THE Engineering Experiment Station of the University of Washington was established in December, 1917, in order to coördinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is twofold:—

- (a) To investigate and to publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural and industrial affairs.
- (b) To undertake extended research and to publish reports on engineering and scientific problems.

The control of the Station is vested in a Station Staff consisting of the President of the University, the Dean of the College of Engineering as ex-officio Director, and seven members of the Faculty. The Staff determines the character of the investigations to be undertaken and supervises the work. For administrative purposes the work of the Station is organized into seven divisions:—

- 1. Forest Products;
- 2. Mining and Metallurgy;
- 3. Chemical Engineering and Industrial Chemistry;
- 4. Civil Engineering;
- 5. Electrical Engineering;
- 6. Mechanical Engineering;
- 7. Physics Standards and Tests.

The results of the investigations are published in the form of bulletins. Requests for copies of the bulletins and inquiries for information on engineering and industrial problems should be addressed to the Engineering Experiment Station, University of Washington, Seattle.

ENGINEERING EXPERIMENT STATION
UNIVERSITY OF WASHINGTON

Eng. Exp. Sta. Series

Bulletin No. 4

A Summary of Mining and Metalliferous
Mineral Resources in the State of
Washington, with Bibliography

ARTHUR HOMER FISCHER

A thesis submitted in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE IN MINING ENGINEERING

Prepared under coöperative agreement between the College of Mines and
the United States Bureau of Mines

Edited by Milnor Roberts



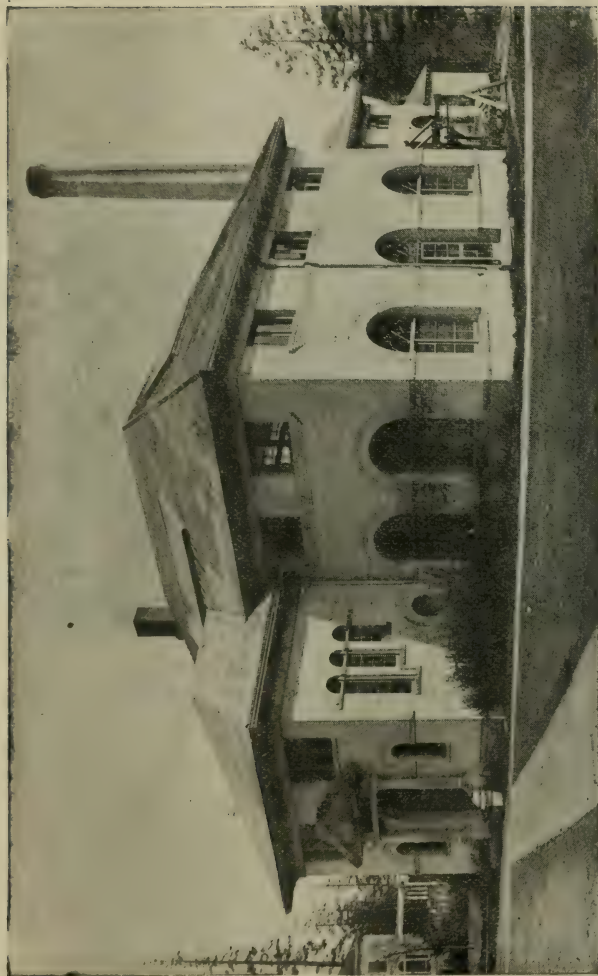
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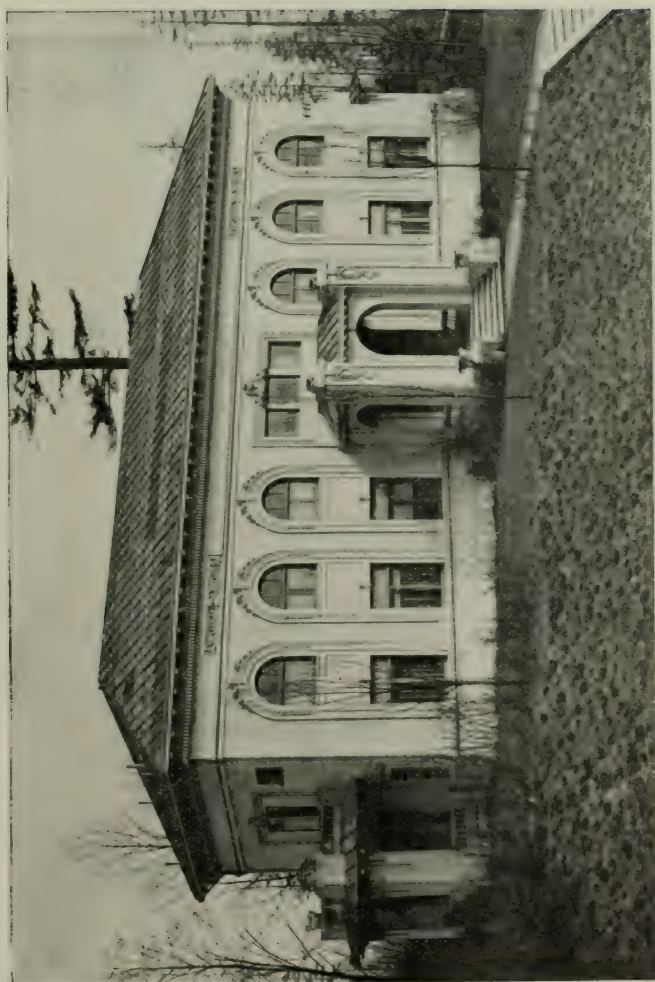
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July 16, 1894



Mines Rescue Training Station
Rescue Training Auto Truck and Crew



Mines Building, University of Washington



Mining and Metallurgical Station

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A Summary of Mining and Metalliferous Mineral Resources in the State of Washington, with Bibliography

FOREWORD

For several years past, many interested persons have felt the need of a compilation and assembling of the references to the available literature and statistical information relating to mining in the State of Washington. While several bibliographies and finding lists relating to mining and geology are now available, none of them are in available form nor sufficiently up-to-date to make them readily usable in a search for references on a given subject. The present work is so arranged that one interested in the mining of a particular economic product, for example, or seeking information regarding a mining property can find a list of the available references. Bulletin No. 12 of the Washington Geological Survey, by Miss Gretchen O'Donnel, published in 1913, ably covers the field of references bearing on the geology and geography of the State, including valuable references to mining articles, but is not a bibliography of mining subjects. A need seems to exist for a single compilation which will obviate the necessity of a search being made by each inquirer through a number of scattered indexes and the files of various journals and other publications.

This need has been felt particularly by the faculty of the College of Mines of the University of Washington, to whom numerous inquiries are directed asking for information regarding mineral deposits of various kinds. The establishment of the United States Bureau of Mines in this State, located at Seattle, has further emphasized the necessity of such a compilation of references, as above referred to. It devolved upon the writer, as a part of his duties as Research Fellow in the College of Mines of the University of Washington and the United States Bureau of Mines, to make such a compilation, and to accompany this assembling of data with a brief summary of the mining situation as it at present exists in this State, and this work is offered in the sincere hope that it will fill in part the need already referred to.

The scope of the work has been limited to references and summaries relating only to the metalliferous resources of the State of Washington, except that occasional notes have been made of mineral deposits of non-metals, gem stones, etc., when such have been found incidentally in the search for references bearing on the subject matter proper. The few references to metallurgical plants, concentrating mills, etc., have been made in the same way, and the list of these is in no sense to be regarded

as even approximately exhaustive. The scope has been further restricted by arbitrarily placing the limits of search for articles at January 1, 1890, and May 1, 1918, except in so far as the writer hereof has taken material from Bulletin No. 12, W. G. S., already referred to. A list of the publications to which references have been made will be found at the beginning of Part III.

The bibliography of references to mineral resources while not exhaustive is believed to be essentially complete, in the sense that practically all the known mineral deposits (to which references have been made in the various magazines and other publications) are listed at least once, and in many cases much oftener.

Part I of the work has been devoted to a summary of the more important metalliferous resources, together with the factors influencing their development. This is followed by Part II, a list of the mining districts of the State, listed under their chief economic metallic product. Part III consists of a bibliography of articles and notes relating to the mining industry, the first portion thereof being a list of articles referring to the State as a whole, the second portion referring to the various counties, and the third portion containing the metallurgical references, the first two sections being classified by the economic metal to which the listed articles refer. Part IV is a finding list of authors, the names being arranged alphabetically; Part V is a finding list of principal articles similarly arranged; Part VI is a finding list of mining properties, districts, and metallurgical plants, similarly arranged, and Part VII is a finding list of mineral products, arranged alphabetically, giving under each heading the counties in which that product occurs. A map of the State of Washington is provided for reference. The United States Geological Survey gave permission to use its map, to which have been added numbers in red which show the location of all mining districts and principal camps.

The writer wishes to acknowledge his indebtedness to Dean Milnor Roberts, of the College of Mines of the University of Washington, for helpful suggestions and criticism; to Mr. Thomas Varley, Superintendent of the Pacific Northwest Mining Experiment Station of the U. S. Bureau of Mines, for his courtesy in extending to the writer the facilities of the Station; to Mr. Will H. Coghill, Metallurgist of the Station, for critical reading of parts of the manuscript; and to Mr. Conrad J. Opperman for assistance in searching the files of publications on geology.

Part I

A SUMMARY OF MINING AND METALLIFEROUS MINERAL RESOURCES IN THE STATE OF WASHINGTON

In the following summary of mining and mineral resources in the State of Washington it has been the aim of the writer to present very briefly the principal features of mining development in the State and to give a very short resumé of the principal mineral resources. For additional information on either of these subjects the reader is referred to articles listed in the bibliography, Part III.

MINING IN WASHINGTON

BEGINNING OF MINING IN WASHINGTON

The history of mining in the State of Washington begins with the gold rush to the Colville country in 1855. The first mining center in the State was Old Fort Colville, on the east bank of the Columbia River, which for thirty years previous to this time had been the chief inland post of the Hudson's Bay Company.

In a very interesting book* by William J. Trimble, Ph. D., the beginnings of the mining industry in this State and adjacent territory are set forth, and the prospector is shown as the forerunner of civilization in this region. The following notes on the beginnings of mining in Washington are freely abstracted from Dr. Trimble's work, which so far as the present writer knows is the only one in its field.

One of the greatest factors in the mining advance was the friendship of the Nez Perce Indians, who alone of the tribes of the Inland Empire were not hostile to miners and farmers. Trouble with the warlike tribes broke out in September, 1855, and continued throughout 1855 and 1856. During the progress of this war General Wool, Commander of the Department of the Pacific, issued the following orders:

"No emigrants or other whites, except the Hudson Bay Company or persons having ceded rights from the Indians, will be permitted to settle or remain in the Indian country, or on land not ceded by treaty confirmed by the Senate and approved by the President of the United States.

"These orders are not, however, to apply to the miners engaged in collecting gold at the Colville mines. . . ."

Probably the custom of the miners of unconscious trespassing and their claim of implied recognition to such rights on the part of the United

* "The Mining Advance Into the Inland Empire," a thesis submitted for the degree of Doctor of Philosophy at the University of Wisconsin, 1914.

States may have influenced the military authorities to make the exception noted in their favor. In general, the country was unsafe for prospecting and trouble with the Indians was frequent. The scrip paid to volunteer soldiers for their services in these uprisings was subsequently used as a medium of exchange, and its presence produced a stimulation in mining. Some miners near Colville continued work, and on November 23, 1857, a meeting was held at Fort Colville and a petition drawn up for the location of a company of soldiers in the valley. A rude government organization was at the same time effected. In the summer of 1858 permanent peace was established in the Indian country, and 1859 witnessed the establishment of new Fort Colville.

The construction of the Mullan road over Mullan Pass in the Rocky Mountains was completed in 1862, and was an event of great importance, as the road was much used by miners working west. The completion of this road made access to the Columbia River easy, and with the beginning of steam navigation on the river, mining activity was greatly stimulated. In 1858 mining began on the Wenatchee River placers; they were at first regarded as highly important but proved evanescent.

The economic results of the mining advance were numerous, including the upbuilding of towns in the community and the encouragement of agriculture and stock-raising. The Puget Sound country, although not directly in the path of this advance, felt permanent effects from it. The social aspects of the movement were such as might be expected when one considers the heterogeneous population of the country. The amusements of the people were varied, including horse-racing, prizefighting, drinking, gambling, dancing, etc. This pioneer time also witnessed the beginning of education and religion. Law and order were evolved, newspapers established, and the beginnings were made upon which the present-day structure of Pacific Northwest development was built.

SUBSEQUENT MINING DEVELOPMENT

The subsequent development of the mining industry has been intermittent rather than constant or gradual. Periods of activity have been followed by periods almost of stagnation, when little prospecting or development work would be undertaken.

Prospectors working south from British Columbia in the early '60s discovered the placer diggings of Ruby Creek in Whatcom County, of the Sultan Basin in Snohomish County, and of the Peshastin and Swauk country near Mount Stuart.

Following these discoveries came those of the iron deposits of Snoqualmie Pass, at that time almost inaccessible, and of the Culver gold-quartz ledge at Blewett, the first to be discovered in the State. In the

early '80s the first silver discovery in the Colville district was made. In the interval between 1870 and 1887, however, but little material development took place, but in the latter year development began in real earnest in widely separated districts of the State. This development continued for several years in both eastern and western Washington. Many failures were encountered, those in gold mining being mainly due to failure to recognize the existence of gold in conditions other than free milling. The discoveries at Monte Cristo, at Index and in the Berlin district, all in western Washington, did much to stimulate interest in that section of the State, but after several years the Monte Cristo district was pronounced "worked out" and the two other districts were called failures insofar as constant ore bodies were concerned. This period of activity in western Washington was followed by a long period of depression, which has shown signs during the last two or three years of coming to an end. Development work during this recent period has been steadily carried on by certain companies in the Index and Monte Cristo districts, and the results may be regarded as promising.

In eastern Washington the progress of exploration and development has been more steady than in the western part of the State, due in great part to the fact that several of the mines in this section have kept up more or less regular production, particularly in northeastern Washington. Encouragement has in this way been given to capital to undertake new developments, which, in general, have been more systematically conducted in this part of the State than in western Washington. However, eastern Washington also has had its periods of depression followed by renewed activity in various regions.

ADVERSE FACTORS IN MINING

The mining development of Washington has been hampered to a great extent by the lack of any large ore bodies, the discovery of which would encourage further exploration. Several properties in the State which have been operated on a commercial scale have worked out one or two small ore shoots and have then discontinued operations. Other factors which have acted to prevent the successful development of mining have been the greatly faulted condition of many of the mineral veins and the difficulties of metallurgical treatment attending the milling and smelting of some of the complex ores.

In the great complex of igneous and metamorphic rocks which make up the Cascade Mountains and the ranges of northeastern Washington faulting is very common, and in the development work of many of the properties the search for the ore body after encountering a fault has cost much money, in many cases without result.

Considering the State as a whole, a majority of the ores are complex and do not yield high recoveries by the ordinary simple processes of milling and concentration. In the two most productive districts in the State, Republic and Monte Cristo, the metallurgical treatment of the ores has been a great problem. In the Republic district many costly mills were erected, only to prove failures to a greater or less degree, while in the Monte Cristo district the complexity of the ores has made concentration a difficult problem. These adverse factors will be taken up more in detail in subsequent paragraphs under the discussion of gold mining.

Lack of transportation facilities in the greater part of the mountainous regions of the State has been a serious obstacle to mining development and in many instances to prospecting except on a very small scale. The three railroad lines crossing the Cascades are located, while on the western slope of the mountains, almost entirely within the boundaries of King County. The regions to the north and south of King County are served by railroad lines on the western side which run some distance toward the divide, but there is still a considerable stretch of country to be traversed by wagon road or pack trail before the outlying spurs or the summit of the range is reached. The difficulties attending the construction of wagon roads in these mountains are great, and as a result pack trails are abundant, the passes at the head of nearly every important stream at the main divide being crossed in this way.

On the eastern slope of the Cascades a similar condition exists, but here even the short lines are lacking. In northeastern Washington railroads serve the principal developed mining sections of Ferry, Okanogan and Stevens counties, but here too are great stretches of country without other highways than poor roads and steep pack trails.

An instance of the effect of transportation on mining development is well shown in the case of the Sunset mine, near Index. For many years this property was idle due to difficulties of transport, but the coming of a logging railroad into the vicinity rendered it possible to make development more than pay its way by shipments of smelting ore.

The Cascade Mountains, and especially their western slope, have a heavy precipitation in the form of rain and snow, which results in the presence of much water in surface workings and prospecting shafts. The difficulty of coping with water while sinking on the ore body has led many prospectors and operators to abandon the vein and begin construction of long adits in the hope of intersecting the ore body at depth, without first proving its existence at the level of the adit. This course has frequently failed of justification, as the ore bodies either did not persist to the assumed depth, or had been displaced by faulting, thus causing great financial loss and resulting often in the suspension of operations.

Another cause operating to hinder development has been poor business management, together with the failure to employ competent engineering advice in the development of properties. Properties have been over-capitalized, development work has been undertaken in an unsystematic manner, concentrating plants have been erected before sufficient development work had been done to warrant this step, and attempts have been made to operate small properties on too large a scale.

THE FUTURE OF MINING

Notwithstanding all the causes which have hampered mining development in this State, Washington has a future as a mineral producer. On account of the small ore bodies which are typical of the State as a whole, we shall probably never witness large scale development such as characterizes mining in certain other States, but it is possible that careful work on a proper scale in many of the now abandoned mines and prospects of the various districts would be productive of successful results. Similarly, conservative development should be applied also to newly discovered deposits.

Improvements in transportation facilities, the building of new railroads and trunk highways over hitherto inaccessible portions of the mountains of the State, the abundant water power which can be used for mine operations and for subsequent ore treatment, the possibilities which this water power affords for the electric smelting of suitable ores of a district without transportation to large plants, the abundance of timber for mine use, — all these things favor a successful prosecution of mining. It is not too much to hope that the combination of these favorable factors will ultimately overcome those which are adverse to successful development.

MINERAL RESOURCES OF WASHINGTON

The principal mineral resources of Washington in the order of their importance are gold, silver, copper, and lead. While this State is not an important producer of any of these metals as compared with some of the States that have exceptional mineral wealth, still its production of gold and silver has in the aggregate been considerable, and its production of copper and lead may eventually become large enough to give it a higher rank than it has so far held as a producer of these metals.

In the following paragraphs will be found a brief summary of the more important metalliferous resources of the State and their occurrence, together with some references to the metallurgical problems of certain districts. In this summary no attempt has been made to treat all the known resources of any one of the metals under discussion, as numerous references to nearly all the known deposits will be found in the bibliography

under Part III hereof, to which the reader is referred for further information. In Part VII will be found a finding list, arranged in alphabetical order by mineral products, of counties noted in the bibliography as having deposits of those products.

ANTIMONY

The production of antimony in the United States as a whole prior to the war was never great, due to the fact that in the mining and reduction of this metal it has been necessary to compete with the Japanese and Chinese, who operate under cheap labor conditions.

In the State of Washington antimony occurs as an accessory mineral in many ore bodies, but in only a few instances has it been regarded as of sufficient importance to be a principal economic product. The Lucky Knock mine at Tonasket, Okanogan County, the Wells-Fargo property in Stevens County, and the Great Republic mine near Berlin, in King County, have been regarded as possible sources of the metal. At the first named property a small amount of metal was smelted in a furnace erected at the property. Shipments have been made from Gold Creek, a tributary of the Methow River in Okanogan County. Antimony also occurs in the Silver Creek district in Snohomish County, in the Camp Creek district in Kittitas County, and Bancroft notes antimony as occurring in the R. E. Lee and Longstreet claims in the Covada district in Ferry County.

ARSENIC

Many of the ores of Washington contain arsenic, some in sufficient quantity to make it a source of profit in smelting, through the production of sublimed arsenic trioxide, the "white arsenic" of commerce. The ores of the Monte Cristo district are very rich in this mineral, which carries with it much of the gold of the district. Monte Cristo ores were treated for a number of years at the smelter of the Puget Sound Reduction Company, at Everett, Snohomish County, and for some time the arsenical gases from the roasters were allowed to escape into the air, but in 1901 an arsenic collecting and refining plant was installed, and Washington had the distinction of being the first State in the Union to produce white arsenic on a commercial scale. The Everett smelter has since been dismantled, but a larger arsenic plant has been operating for several years past at the Tacoma smelter, where refined white arsenic of a very high grade is produced.

Arsenical ores occur also in many other parts of the Cascade Mountains and in northeastern Washington. They are found near Berlin, King County; in the Twisp and Squaw Creek districts, Okanogan County; in the Stillaguamish district, Snohomish County, and in other places. In addition to ores carrying arsenic as an accessory mineral, deposits of

realgar, arsenic sulphide, exist in a number of places in the State. Perhaps the best known of these is at Mineral in northern Lewis County, where white arsenic was produced for a time. Another deposit of realgar occurs near Clear Lake in Skagit County, but so far as the writer knows it has not been worked on a commercial scale. Realgar is known to occur also in the Monte Cristo district.

CHROMIUM

The occurrences of chromium in Washington are few in number. Deposits of chromite in place on Cypress Island, Skagit County, have been worked to some extent and carload shipments of high-grade ore have been made. These deposits occur at several places, scattered over a large portion of the island. Concentration tests of these ores have shown that it is possible to produce marketable chromite from the lower grade portions. The concentration products vary from 40 to 50 per cent chromite oxide, Cr_2O_3 , depending on the size to which the ore is crushed.

Another deposit of chromite is reported from the Sultan Basin in Snohomish County. Chromite is present in many of the black sands of the beaches of the Pacific Coast and Straits of Juan de Fuca. References have been found noting the presence of chromite in some of the Cle Elum ores, and chromium is shown in some analyses of these ores noted by the writer. Chromite ore is found also in the mountains a few miles southwest of Mount Baker.

At the present war prices of chromium it is possible to work profitably many relatively low-grade deposits that under ordinary economic conditions would not be commercially available. This fact has caused a great stimulation of interest in prospecting for chromite, as a result of which some new deposits may be found in Washington.

COPPER

Copper minerals are the most widely distributed metalliferous minerals in Washington, veins in nearly all the districts of the State carrying more or less of this metal. Copper ores of various kinds, chiefly tetrahedrite, chalcopyrite, chalcocite, and bornite, occur in widely separated parts of the State, but their development has been very backward, the total production in the State being probably under 11,000,000 pounds. The adverse factors in mining already noted have been especially active in hindering the development of copper mining. Another factor which formerly hindered copper development was the low price of the metal, which for a long time discouraged efforts to develop this branch of the mineral industry in the State. In 1915, due to the European war, copper prices were greatly increased, and in 1916 Washington produced 2,473,181 pounds of copper, more than double the production of 1915.

The most important copper district in Washington is the Chewelah in Stevens County, the principal mine of the district being that of the United Copper Company. Other places in northeastern Washington in Stevens and Ferry counties also contributed to the production in 1916. Some of the copper ores of this section, while not of high grade, are acceptable to smelters on account of their fluxing properties.

The Index district in Snohomish County at one time gave promise of becoming an important producer, but the failure of the Ethel mine, brought about by the construction of a long adit which did not strike the assumed ore body it was intended to develop, resulted in discouraging many operators and investors from putting the necessary development capital into the properties of the district. However, a few properties have been working at intervals, and one of these in particular, the old Sunset mine on Trout Creek, in the past two years has shipped hand-sorted ores containing half a million pounds of copper. A mill is being erected and the property should become a producer of concentrate in the very near future. It is expected that the resumption of operations at this property will revive Index as a mining camp.

At Dutch Miller Gap in King County are deposits of high-grade copper ores, but lack of transportation has rendered commercial operation here out of the question. The properties are at the head of the middle fork of the Snoqualmie River and accessible only by pack trail from the east and west.

Native copper is found frequently in this State in basis lavas, in widely separated localities, but its presence in these rocks has not yet proven an indication of a deposit of any commercial importance. None of these native copper occurrences are of sufficient extent, so far as known, to be worked as sources of the metal.

GOLD

The total gold production of Washington to date has been more than \$27,000,000, derived largely from a few mining districts. Of the more than thirty mining districts in which gold is the principal economic mineral, five are much more important than the others. These are the Peshastin, Republic, Monte Cristo, Mount Baker, and the Swauk (placer) districts.

The Peshastin district in Chelan County is one of the oldest in the State. It was first worked for placer gold in the early '60s, since which time it has produced much wealth from its placer and lode mines. The ores of the lode mines of the district were at first free milling and were originally worked by means of arrastres and later by stamp mills in which the gold was recovered by amalgamation. The free gold occurred as stringers and flakes in quartz veins in serpentine. At greater depth

it was found necessary to follow amalgamation by concentration and cyanidation, and the mills of the district are now equipped with the necessary machinery for this practice.

A factor which has interfered with mining progress in this district has been the "pockety" nature of the ore. These pockets, while often very rich, are so scattered as to make much "dead work" necessary in underground operations. At the present time there is but little activity in this camp.

The Republic district in Ferry County is a comparatively recent camp, the first discovery having been made in 1896. The ore was first worked by amalgamation but the results were unsatisfactory. The extractions of gold by this method were very low, and a study of the ores showed that some of the gold was not free milling, and that some of it that was in this condition was in a state of exceedingly fine division, requiring a much finer comminution than was customary in stamp battery practice. After this discovery fine grinding and cyaniding either with or without preliminary roasting was attempted, and it greatly improved the results, but at such an increased cost (owing to the great hardness of the ore) as to make the economic value of the process questionable. Chlorination roasting and leaching also met with indifferent success. Many prominent metallurgists have worked on this problem, but the results of the research to date have not materialized into any markedly successful process. The mills have been repeatedly closed down and reopened to try new methods of ore treatment which have not fulfilled the expectations of their promoters.

Direct smelting of the ores was for a long time regarded as unprofitable because of their highly siliceous character which made them at this period unwelcome at the nearest smelters, and the average tenor of the ore was not such as to warrant too great expense of penalties in smelting or of transportation to other smelters to avoid such penalties. Later developments in mining in other districts and consequent changes in smelter practice, together with better transportation and lower freight rates from the district, have to a certain extent operated to render more profitable the direct smelter treatment of these dry ores. For articles dealing with this phase of the situation at Republic the reader is referred to the bibliography in Part III hereof under the heading of Metallurgy (Ferry County).

Republic camp is not hampered by lack of well defined ore bodies as is the Peshastin district. The veins are uniform and well defined. At the present time there is not much active development in this camp, but small shipments are taking place regularly.

The Monte Cristo mining district in Snohomish County was discov-

ered in 1889 and was regarded as of such promise by eminent engineers that in 1893 a railroad was constructed at great expense and in the face of great engineering difficulties for the purpose of developing the mines. This is the only road of any considerable length which has been constructed in this State solely for mine purposes. Prior to the construction of this road the camp was almost inaccessible, being reached by pack trail and wagon road from Arlington and Darrington up the Sauk River or by pack trail from Index over the divide between Silver Creek and the south fork of the Sauk.

The district has produced to date about \$7,000,000 in gold. It was at first believed that the ore bodies of the district would not persist at depth, but subsequent developments, including those of the last two years, have given a more favorable outlook.

Two factors have been adverse to successful operation in this district. The greater of these factors has been perhaps the formation of numerous subsidiary companies to perform the various operations involved in handling the output of the camp from the mines to the smelters. Mining companies, tramway companies, concentrating companies, and the railroad company all had to make a profit, with the result that instead of one fair mining profit from the operations it was necessary to make several corporations pay dividends. The ore value was not high enough to stand heavy overhead charges, and the result was the ultimate closing down of the principal mines of the camp. The railroad was later taken over by the Northern Pacific Railway Company and operated by it for a time, until the caving of some of the tunnels stopped traffic and suspended practically all activity at Monte Cristo and at other camps along the line. Within the last few years the road has been reopened under lease to a lumber company, and Monte Cristo and other districts have been given an opportunity for new development. The more important mines of the camp have been consolidated into two large groups, and several smaller properties also are undergoing development. At the present writing it seems probable that the near future will see Monte Cristo again shipping ore and concentrates.

The lesser adverse factor in this district has been the exceedingly complex nature of the ore, which carries gold, copper, lead, zinc, iron, arsenic, and antimony. Gold occurs to some extent in nearly all the veins, although mainly in those richest in arsenic. The complexity of the ore has resulted in lowering the commercial value of the concentrates from a smelting standpoint. Although some work in differential flotation has been undertaken by metallurgists with a view to the elimination of penalties by making concentrates which would be more acceptable to smelters, little success has so far attended these efforts. In passing it might be stated

that a somewhat similar problem attends the treatment of ores of certain portions of northeastern Washington, notably the Ruby and Conconully districts in Okanogan County. It is not too much to expect that a careful and intelligent continuation of the research will solve the problems and render these complex ores economically available to a greater extent than at present.

The Mount Baker district in Whatcom County presents no difficult metallurgical problems in its gold ores, as the values are easily recovered by amalgamation and cyanidation, and the extractions are high. Although but little is heard about the mines of this district, it contains some properties that have been consistent producers, and which are at present responsible for a very large share of the gold output of Washington.

The Swauk placer district in Kittitas County is another camp about which little is heard but which is producing steadily. It is essentially a country of small scale, individual operations which have produced in the aggregate much gold and which are still being profitably worked in the manner stated. While the district contains some lode mines, its principal importance has been derived from its placer deposits. It is readily accessible from Cle Elum in Kittitas County or from Blewett in Chelan County by stage lines.

Mention should be made of the beach sand deposits of the Pacific Coast of Washington, which together with the sands of some parts of the Straits of San Juan de Fuca have been operated in a small way for many years and may still be regarded as possible sources of gold. While many of these beach sands contain appreciable quantities of gold, in general the difficulties attending its recovery entail so much expense as to make the sands of doubtful economic importance. The gold in these sands is usually very fine and is associated with heavy minerals in the sand which make mechanical separation very difficult, while chemical methods of treatment are too expensive to be economically feasible. Moreover, the number of deposits of this sand which can be worked at all is decidedly limited.

Other districts producing gold are listed in Part II of this work. References to them will be found under their proper heading in the bibliography comprising Part III.

IRON

The subject of iron ore resources of Washington is presented in very complete form in Bulletin No. 2, University of Washington, Bureau of Industrial Research, "An Investigation of the Iron Ore Resources of the Northwest," by William Harrison Whittier, Research Fellow (published by the University in 1917). The following brief summary of the iron resources of the State is freely abstracted from this publication.

The principal iron ore deposits of Washington are included in four districts: The Cle Elum in Kittitas County, the Snoqualmie Pass in King County, the Hamilton in Skagit County, and the Colville and Valley districts in Stevens County.

The Cle Elum ores have been the subject of considerable study, and several good articles covering these deposits will be found listed in the bibliography in Part III of this work. These ore bodies are located on the Cle Elum River about twenty-three or twenty-four miles above its junction with the Yakima. The iron ores are presumably sedimentary in origin and are mixtures of magnetite and hematite. Other iron ores occur in the country lying immediately east of these beds and at other points in the vicinity.

The Snoqualmie Pass area contains two well known magnetite deposits, the Denny and Guye prospects. In the Denny prospect the ore occurs as nodules up to one foot in diameter, associated with some pyrite. In the Guye prospect the magnetite occurs in larger quantities than in the Denny as a replacement deposit in limestone near a granodiorite contact.

The Hamilton district contains ores which have been used as a "mix" with Texada ores in the manufacture of iron in the Irondale furnace, near Port Townsend. The Hamilton deposits, which occur at intervals for several miles along the southerly wall of the Skagit valley, are favorably situated as regards fuel, fluxes, and transportation. They are more or less magnetic and contain considerable manganese and phosphorus.

The deposits at Valley, Stevens County, consist of limonite, hematite and magnetite. They are of considerable extent and carry a high percentage of iron, are rather high in sulphur and phosphorus, but low in silica and should be good mixing ores.

The Colville (Clugston Creek) deposits are largely limonite ranging from bog ore to ore of a cherty character; they are of rather limited extent.

In the Belcher district of Ferry County there is a deposit of magnetic on the Copper Key claim, a mine which has been worked for gold and silver. This deposit may become of economic importance.

Other deposits occur in the Lake Cushman district, Mason County, in the Black Hills of Grays Harbor County, and near Chimacum in Jefferson County. While none of them are of much importance as sources of iron, the Lake Cushman deposit promises to become a source of manganese.

In addition to the deposits mentioned, attempts have been made from time to time to utilize the black-sand beach deposits of the west coast of Washington as a source of iron. The difficulty in attempts of this kind has been to get a product free from deleterious accessory minerals, par-

ticularly ilmenite, and to produce a concentrate of commercial grade at a cost which would render these deposits economically available.

LEAD

Prior to 1915 the maximum production of Washington lead smelted in the State had been in the years from 1907 to 1911, when it ranged from 339 to 612 short tons annually, except in 1909, when it fell to 120 tons. In 1912 the production dropped to 53 tons and in 1915 to 11 tons. These figures are for lead produced and refined in Washington. It must be borne in mind that some of the ore mined in this State has been smelted at points outside the State. In 1914 the actual mine production was $32\frac{3}{4}$ short tons and in 1915 $147\frac{1}{2}$ short tons. In 1916 217 short tons were produced and refined in Washington and 2,001 tons smelted in Canada from Washington ore. This great increase was due to the discoveries of lead ore chimneys at the Electric Point mine near Northport, Stevens County. These ores are extremely rich in lead but carry little silver. Other discoveries at Northport during the last two years have further stimulated lead mining in this State.

The Bossburg district in Stevens County produced some lead from galena and was the heaviest producer in the State until the Electric Point discoveries were made. Another district in Stevens County which at one time made a considerable production of lead is the Colville. The principal producer in this district was the Old Dominion mine mentioned under the discussion of silver in this summary.

In Okanogan County the Ruby and Conconully districts (also mentioned under the discussion of silver deposits) are potential sources of lead production, as are also the Metaline district in Pend Oreille County and the Thunder Creek district in Skagit County.

MANGANESE

With two exceptions the known manganese ores of Washington lie in the topographic division known as the Olympic peninsula. The Olympic manganese deposits are mainly comprised in a belt two to three miles wide on the south and east flanks of the Olympics, extending from a point near Lake Quinault easterly to Lake Cushman and thence northerly to the head of Dungeness River; manganese ores also occur near Hump-tulips in Grays Harbor County. These ores occur in association with copper or iron. The manganese minerals present are psilomelane, pink rhodonite, and some rhodochrosite. An interesting occurrence of the last named mineral is at the Tubal Cain mine in Jefferson County, where the manganese occurs in association with copper. These Olympic deposits so far as explorations show are shallow, and of a grade varying from

17 to 36 per cent. manganese. So far relatively little development work has been done on the greater part of these deposits, and they have not been worked steadily, although occasional shipments have been made from them.

The exceptions noted in the preceding paragraph are a deposit of manganese near Anacortes similar in occurrence to those in the Olympics, and one of psilomelane near Omak, Okanogan County.

MOLYBDENUM

Molybdenum as the sulphide, molybdenite, is of widespread occurrence in Washington, although not generally in sufficient quantity to make its mining profitable under normal conditions. Deposits of molybdenite are known to occur in many parts of the Cascade range north of Mount St. Helens, and in all the counties of northeastern Washington.

One of the deposits in Chelan County, that of the Crown Point mine, has yielded a considerable quantity of molybdenum ore which was milled at the mine, but the property is not now being worked. It has been the source of many of the finest specimens of molybdenite ever produced. The deposit here occurs in a "blanket" quartz vein, outcropping on the face of a cliff at the head of Railroad Creek, west of Lake Chelan. For descriptions of this deposit the reader is referred to the bibliography.

So far as the writer knows, none of the other deposits of molybdenum have been developed on a commercial scale. One of the obstacles to this development of molybdenite ores from a commercial standpoint has been the fact that only concentrates carrying from 50 to 80 per cent. molybdenite have been acceptable to the buyers of this product. The production of concentrates of this high grade is very difficult when attempted by ordinary methods of treatment, and many special methods have been devised in attempts to solve this problem. The difficulty lies in the "sliming" and floating tendency of molybdenite, which occasions great losses in treatment by water concentration, even with material of relatively large size. Air and electrostatic treatment, and surface and oil froth flotation have all been tried with varying degrees of success.

The problem in Washington is further complicated by the fact that many of the deposits of molybdenite occur in association with chalcopyrite. The presence of copper in excess of 1 to 2 per cent. in the molybdenite concentrate renders the product unsalable, and smaller percentages than those indicated greatly lower the value of the concentrate.

However, under the stimulus of war conditions, it is not improbable that mines containing molybdenum as an accessory mineral, such as the Sunset Copper mine near Index, may find it profitable to make a separation from copper in order to get a molybdenum product.

NICKEL

While nickel has been reported from a number of places in Washington, there is only one deposit which has been considered a possible source of the metal on a commercial scale. This is the Congress mine in the San Poil district in Ferry County, which is described by Bancroft in Bulletin 550, U. S. Geological Survey. Specimens from this mine showed 5 per cent. of nickel.

In Stevens County several occurrences of nickel have been noted, especially one near Northport and another in Cedar Canyon; in Okanogan County nickel occurs at the Stepstone property, twelve miles north of Nespelem.

Near Mount Stuart several attempts have been made to develop nickel properties, but none of them have materialized into commercial producers. In this district there occur so-called "nickel dikes," which contain a trace of nickel but are not to be considered as ores of this metal. For descriptions of these dikes, the reader is referred to the Mount Stuart folio of the Geologic Atlas of the United States.

Nickel has been reported from a point at the head of the Cowlitz River in Lewis County, and from a point near Sedro-Woolley, Skagit County.

PLATINUM

Stream platinum has been taken from Negro Creek near Mount Stuart; from Mad River in Chelan County, north of Leavenworth; from the Similkameen River in Okanogan County, from the south fork of Lewis River in Clarke County, and from the gold placers on the ocean beaches.

Platinum in place has been reported from a chromite deposit near Anacortes, probably the one on Cypress Island, and on Little Mount Chopaka, Okanogan County; little is known concerning these occurrences. On the whole Washington has produced very little platinum.

QUICKSILVER

Cinnabar, mercury sulphide, is the chief ore of quicksilver. It often occurs merely as a red stain on rocks in shatter zones, also in small masses or disseminations. While the content of quicksilver in such ores is usually very small, generally less than 1 per cent., the cost of treatment is so slight that at the present war prices of quicksilver many low-grade deposits might be profitably worked.

The simple metallurgy of quicksilver and the relatively high extraction possible by direct furnace treatment on very low-grade ores have operated to hinder attempts at concentration before retorting. The usual practice in the treatment of the ores is to distill off the mercury in furnaces of various types and then condense the mercury vapor by means

of some kind of cooling system. The cost and losses incurred in concentration have hitherto been deemed too great to make it worth while to attempt any ore dressing before furnace treatment. The present tendency, however, is rather toward some preliminary concentration in order to save the cost of erection of furnaces and condensers large enough to handle a given tonnage. High concentration ratios with good extractions are possible in laboratory flotation tests with low-grade ores, thus indicating the feasibility of the use of very small retorting equipment to treat a large tonnage of ore.

Gravity concentration on quicksilver ores usually results in considerable loss through sliming, as cinnabar is very floatable and passes readily over the slimes side of the table. Some attention has been devoted to concentration of these ores by froth flotation, with promising results. Laboratory experiments on flotation of an ore from Oregon, carrying 0.15 per cent. mercury, resulted in a concentrate running over 50 per cent. mercury, with an extraction of approximately 80 per cent.

Quicksilver ores occur in many parts of Washington, the best known deposits being at Morton, in northern Lewis County. Retorting has been carried on here for some time with good results. Deposits of quicksilver ores have also been noted in Kittitas County at the mine of the Washington Quicksilver Company and on the Teanaway River near Mount Stuart. Reference has also been found to the installation of a furnace at the Eclipse mine in the Stillaguamish district in Snohomish County. In Chelan County cinnabar has been reported from the "Leavenworth Prospect," from Squaw Saddle Mountain, three miles from Wenatchee, and at a point near Orondo.

In view of the possibilities of treatment as outlined above it would seem that quicksilver mining might be profitably carried on in this State even under the handicap of a material decline in war prices of the metal.

SILVER

The total production of silver in the State of Washington to the end of 1917 has been about 7,000,000 fine ounces. This production has in most instances been derived from ores of other metals, chiefly gold, copper and lead. By far the greater bulk of the silver production in the State today comes from the siliceous gold ores of Republic, Ferry County, and from the copper concentrates from Chewelah, Stevens County. Silver occurs also in the Covada and San Poil districts in Ferry County, in the Cedar Canyon, Silver Queen and other districts of Stevens County, and is present to some extent in the ores of some of the properties in the Mount Baker gold district, in the Thunder Creek basin in Skagit County, which is said to contain lead deposits rich in silver, and in the Peshastin district,

with gold. In the Crystal district in Lincoln County it is the principal economic mineral.

Besides the sources of silver already noted in northeastern Washington, the Ruby and Conconully districts in Okanogan County contain silver-lead deposits of varying grade with accessory copper and zinc and a little gold, while some of the gold ores of the Nespelem and Palmer Mountain districts also carry silver. The treatment of the low-grade ores of the Ruby and Conconully districts has been difficult, owing to their complex nature, but during the last two years laboratory metallurgical investigations have given such encouraging results as to make it seem probable that these ores may be profitably worked in the near future, particularly in view of the present high war prices of silver. For details of these investigations the reader is referred to Bulletin 640-b, U. S. Geological Survey.

One of the oldest mines in the State, the old Dominion in the Colville district, Stevens County, was at one time a heavy producer of silver and lead, but of late years its operation has been intermittent and its production practically negligible.

TIN

While tin has been reported from several localities in Washington — namely, from Whatcom County, from Kittitas County, from Stevens County, and from the vicinity of Spokane — the latter deposit is apparently the only one which is authentic or of such a nature as to offer any possibility of being a source of the metal.

Some concentration tests of samples of the Spokane ore, made by the writer under the direction of Mr. Thomas Varley, Superintendent of the U. S. Bureau of Mines Experiment Station, Seattle, gave an extraction of 90 per cent. of the tin in the ore, with concentrates varying from 52½ per cent. to 67 per cent. tin, depending on the sizing. The crude ore tested had a content of 1.82 per cent metallic tin.

Many articles have been written concerning the Spokane tin deposit, and the reader is referred to the articles listed in the bibliography under the heading "Spokane County" for further information concerning this property.

At one time it was believed that a large deposit of tin ore existed in Kitsap County in the vicinity of Wild Cat Lake near Chico, but there have been no subsequent developments to indicate the authenticity of this deposit. An examination of this property was conducted in 1906 by the writer, acting in conjunction with other persons. The workings were carefully sampled and many assays made, but none revealed the presence of tin.

TUNGSTEN

The tungsten deposits of Washington are located chiefly in the northeastern part of the State in Stevens and Okanogan counties, although the metal is known to occur in other parts of the State as well.

The Stevens County deposits have been worked on a commercial scale and have been the source of considerable tungsten. There are three properties in this county where tungsten occurs in commercial quantities: The Germania in the Deertrail (Cedar Canyon) district and the Blue Grouse and Tungsten King properties near Loon Lake. All these properties have been developed more or less, and have shipped concentrates in the past. Other places in Stevens County which have reported tungsten will be found listed in the bibliography. Tungsten has been found associated with copper near Chewelah.

Near Loomis, in Okanogan County, a large deposit of tungsten is said to exist. It is also reported at the Copper World Extension mine and at Cathedral Peak in this county.

In Ferry County, wolframite has been reported from a point near Keller, and scheelite has been found in the Silver Leaf mine near Covada. Scheelite has been reported also from the tin deposit at Silver Hill near Spokane.

In Yakima County tungsten deposits have been prospected near Bumping Lake in the Cascade Mountains with promising results.

ZINC

Prior to 1915 Washington's production of zinc was negligible, but in that year the production amounted to 122 short tons, and in 1916 over 846 short tons were produced. This great increase was due to developments in the Northport district in Stevens County, where the lead ores are usually accompanied by zinc. In this district zinc carbonate ores of shipping grade also occur.

In the Metaline district in Pend Oreille County the zinc mineralization is as wide as that of the lead, according to Bancroft, some of the ore being carbonate shipping ore, while the remainder is concentrating ore consisting of sphalerite and galena.

Other zinc ore deposits are in the Bald Mountain district in Skamania County, near Keller in Ferry County, in the Upper Methow, Okanogan County, near Mount Baker in Whatcom County and at several other points in the northern Cascades. A deposit of zinc ores is also said to occur near Arlington in Snohomish County.

Part II

THE MINING DISTRICTS OF WASHINGTON

(See accompanying map)

The following list of Mining Districts of Washington is a rearrangement of the list given for the State in Bulletin 507, U. S. Geological Survey, "The Mining Districts of the Western United States," by James M. Hill, published in 1912. The districts are classified for the present work under the heading for the principal economic mineral for the district, instead of under the names of the various counties.

The arrangement of the data under each district is similar to that used in Bulletin 507, except that references to publications of the Survey dealing with the various districts are here omitted, as practically all these references, together with many others, will be found in Part III of this work under their proper heading. The arrangement here used consists of the following items:

1. A reference number for each district.
2. The names and subnames of the district.
3. A list of the metals produced in the camp, in the order of their importance. "For some districts the list of metals produced is followed by 'Pl', signifying that the production is largely from placer mines, or by 'Pl and D', or 'D and Pl', signifying that the production is from both deep and placer mines, the more important source being placed first. In all districts not marked in this way the production is derived from deep mines.
4. "The shipping point of the camp, with the distances and direction of the camp from it and the railroad on which it is located.—" The following abbreviations are used for the railroads of the State:

B. B. & B. C. R. R.	Bellingham Bay & British Columbia Railroad.
C. M. & St. P. Ry.	Chicago, Milwaukee & St. Paul Railway.
G. N. Ry.	Great Northern Railway.
I. & W. N. R. R.	Idaho & Washington Northern Railroad.
N. P. Ry.	Northern Pacific Railway.
S. Pt. A. & W. Ry.	Seattle, Pt. Angeles & Western Railway.
T. E. R. R.	Tacoma Eastern Railroad.
5. "A statement of the geologic formation of the region, intended to give simply a general idea of the rocks in which the deposits occur."
6. "The kind of deposits found in the region."

Under each of the primary divisions of this list the districts are arranged alphabetically by the counties in which they are located. An index of the names of the districts arranged in alphabetical order will be found at the end of the list, for convenience in finding the reference number of any particular district.

The accompanying map shows the location of all mining districts and principal camps. It is based on a map prepared and printed by the United State Geological Survey, the numbers in red being added by permission of the Survey.

GOLD DISTRICTS

1. Bridge Creek (Stehekin), Chelan Co. Gold, silver.
60 miles N.W. Chelan, G. N. R. Granite, gneiss and schist. Veins.
2. Entiat, Chelan Co. Gold, silver.
Station, G. N. Ry. Schists. Veins.
3. Horseshoe Basin (Pershall), Chelan Co. Gold, silver, lead, copper.
70 miles N.W. Chelan, G. N. Ry.
4. Lakeside, Chelan Co. Gold.
At Chelan Station, G. N. Ry.
5. Leavenworth, Chelan Co. Gold, Silver. (D, Pl.)
Station, G. N. Ry.
6. Peshastin (Blewett), Chelan Co. Gold, silver, quicksilver. (D, Pl.)
12 miles S. Dryden, G. N. Ry. Paleozoic sediments, peridotite, granodiorite. Veins.
7. Railroad Creek, Chelan Co. Gold, silver, copper, molybdenum.
50 miles N.W. Chelan, G. N. Ry. Gneiss and schist intruded by granite. Veins.
8. Wenatchee, Chelan Co. Gold.
7 miles W. Wenatchee, G. N. Ry. Sediment cut by rhyolite. Veins.
9. Ozette River, Clallam Co. Gold. (Pl.)
40 miles W. Twin Rivers, S. Pt. A. & W. Ry. Beach placers.
10. Shishi Beach, Clallam Co. Gold. (Pl.)
40 miles W. Twin Rivers, S. Pt. A. & W. Ry. Beach gravels.
11. Yellow Banks, Clallam Co. Gold. (Pl.)
40 miles W. Twin Rivers, S. Pt. A. & W. Ry. Beach gravels.
12. Columbia River, Ferry Co. Gold. (Pl.)
11 miles N.E. Creston, N. P. Ry. Stream gravels.
13. Danville, Ferry Co. Gold, copper, silver.
Station, G. N. Ry. Paleozoic sediments and greenstones. Replacements and veins.
14. Republic (Eureka), Ferry Co. Gold, silver.
Station, G. N. Ry. Tertiary volcanics. Veins.

15. Money Creek (Miller River), King Co. Gold, silver, lead, copper, antimony, iron.
Berlin Station, G. N. Ry. Granite. Veins.
16. Fish Lake, Kittitas Co. Gold, silver, copper.
40 miles N. Roslyn, N. P. Ry.
17. Swauk (Liberty), Kittitas Co. Gold, silver, iron. (D, Pl.)
15 miles E.N.E. Cle Elum, N. P. Ry. C. M. & St. P. Ry. Tertiary sediments cut by basalt. Veins.
18. Myers Creek (Chesaw), Okanogan Co. Gold, silver, copper. (D, Pl.)
5 miles S. Myncaster, Canada, G. N. Ry. Paleozoic sediments and greenstones intruded by granite and syenite. Veins, contact, metamorphic.
19. Moses (Nespelem, Park City), Okanogan County. Gold, silver, lead, copper.
37 miles N. Almira, N. P. Ry. Veins.
20. Nighthawk, Okanogan Co. Gold, silver.
Station, G. N. Ry. Paleozoic sediments and greenstones intruded by granite. Veins.
21. Palmer Mountain (Wannacut Lake, Loomis), Okanogan Co. Gold, silver, copper.
14 miles S. Nighthawk, G. N. Ry. Greenstones and paleozoic sediments intruded by granite. Veins, disseminations.
22. Squaw Creek (Methow), Okanogan Co. Gold, silver, copper, antimony.
10 miles N.W. Pateros, G. N. Ry. Gneiss intruded by granite. Veins.
23. Twisp, Okanogan Co. Gold, silver, copper.
30 miles N.N.W. Pateros, G. N. Ry.
24. Wauconda, Okanogan Co. Gold, silver.
19 miles N.W. Republic, G. N. Ry. Paleozoic sediments intruded by granite. Veins.
25. Darrington, Snohomish Co. Gold, silver, copper.
Station, N. P. Ry. Schist, slate, serpentine. Veins.
26. Granite Falls, Snohomish Co. Gold, silver, copper.
Station, N. P. Ry.
27. Monte Cristo, Snohomish Co. Gold, silver, copper, arsenic.
Station, N. P. Ry. Mesozoic granites and Tertiary volcanics. Veins.
28. Meyers Falls, Stevens Co. Gold, silver, copper.
Station, G. N. Ry. Paleozoic sediments cut by porphyry. Veins.
29. Orient, Stevens Co. Gold, silver, copper.
Station, G. N. Ry. Tertiary volcanics. Veins, impregnations.
30. Mount Baker, Whatcom Co. Gold, silver, zinc, copper.

12 miles N.E. Glacier, B. B. & B. C. R. R. Metamorphosed sediments cut by porphyry. Veins.

31. Slate Creek (Barron), Whatcom Co. Gold, silver. (Pl.)

60 miles N.E. Rockport, G. N. Ry. Stream gravels.

See also 34, 35, 36, 40, 41, 42, 44, 45, 46, 47, 48.

SILVER DISTRICTS

32. Meteor (Covada), Ferry Co. Silver, lead, antimony.

34 miles S.S.W. Meyers Falls, G. N. Ry. Metamorphosed Paleozoic sediments cut by diorite. Veins.

33. Crystal, Lincoln Co. Silver, lead.

15 miles N. Davenport, N. P. Ry. Schists and slates. Veins.

34. Upper Methow, Okanogan Co. Silver, lead, copper, gold.

50 miles N.N.W. Pateros, G. N. Ry. Gneiss and schist intruded by granite. Veins.

35. Thunder Creek, Skagit Co. Silver, gold, copper, lead.

36 miles E. Rockport, G. N. Ry. Veins.

36. Deer Trail (Cedar Canyon), Stevens Co. Silver, lead, tungsten, gold, copper.

18 miles W.S.W. Springdale, G. N. Ry. Paleozoic sediments cut by acidic and basic dikes.

See also 1, 2, 3, 5, 6, 7, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 39, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53.

COPPER DISTRICTS

37. Belcher, Ferry Co. Copper.

Belcher Siding, G. N. Ry. Paleozoic sediments cut by quartz monzonite. Replacements, contact metamorphic.

38. Lone Star, Ferry Co. Copper.

6 miles W. Danville, G. N. Ry. Paleozoic sediments cut by quartz monzonites. Veins, replacements.

39. San Poil, Ferry Co. Copper, lead, silver, nickel.

30 miles N. Wilbur, N. P. Ry. Metamorphosed Paleozoic sediments cut by quartz monzonite. Veins, replacements.

40. Osoyoos Lake (Oroville), Okanogan Co. Copper, gold.

Oroville Station, G. N. Ry. Paleozoic sediments and greenstones cut by andesite. Veins, disseminations.

41. Carbon River, Pierce Co. Copper, gold.

Fairfax Station, N. P. Ry. Syenite. Veins.

42. Bald Mountain, Skagit Co. Copper, gold.

10 miles S. Lyman, G. N. Ry. Schist and slate cut by diorite. Veins.

43. St. Helens, Skamania and Lewis Cos. Copper, silver, lead, zinc.

41 miles E. Castle Rock, N. P. Ry. Syenite cut by porphyry. Veins.

44. Index, Snohomish Co. Copper, silver, gold, molybdenum.
Station, G. N. Ry. Granodiorite cut by basis dikes. Veins.
45. Silver Creek, Snohomish Co. Copper, gold, silver, lead.
15 miles N.E. Index, G. N. Ry. Granite and Tertiary volcanics. Veins.
46. Stilaguamish (Silverton), Snohomish Co. Copper, gold, silver, lead.
Station, N. P. Ry. Granite, diorite. Veins.
47. Chewelah, Stevens Co. Copper, silver, lead, zinc, gold, iron, molybdenum.
Station, G. N. Ry. Paleozoic sediments cut by diorite and other basic intrusives. Veins.
See also 3, 7, 13, 15, 16, 18, 19, 21, 22, 23, 25, 26, 27, 28, 29, 30, 34, 35, 36, 48.

LEAD DISTRICTS

48. Conconully (Ruby), Okanogan Co. Lead, silver, gold, copper.
26 miles S. Nighthawk, G. N. Ry. Granite, schist and gneiss cut by dikes. Veins.
49. Bossburg, Stevens Co. Lead, silver.
Station, G. N. Ry. Paleozoic sediments. Replacements. Veins.
50. Metaline, Pend Oreille Co. Lead, zinc, silver.
Station, I. & W. N. R. R. Paleozoic sediments. Disseminations and replacements.
51. Northport, Stevens Co. Lead, silver, zinc.
Station, G. N. Ry. Paleozoic sediments cut by acidic and basic dikes. Veins, replacements.
52. Old Dominion (Colville), Stevens Co. Lead, silver.
7 miles E. Colville, G. N. Ry. Paleozoic sediments cut by granite. Contact metamorphic.
53. Silver Queen, Stevens Co. Lead, silver.
8 miles S. Meyers Falls, G. N. Ry. Paleozoic sediments cut by granite. Replacements, veins.
See also 3, 15, 19, 32, 33, 34, 35, 36, 39, 43, 45, 46, 47.

IRON DISTRICTS

54. Snoqualmie Pass, King Co. Iron.
3 miles E. Rockdale, C. M. & St. P. Ry. Marble, limestone and granite. Bedded.
55. Hamilton, Skagit Co. Iron.
Hamilton Station, G. N. Ry. Sandstone, limestone, shale, slate. Bedded.
56. Deep Creek Lake, Stevens Co. Iron.
12 miles S.E. Northport, G. N. Ry. Granite, Paleozoic sediments. Bedded.
See also 15, 17, 47.

ARSENIC DISTRICTS

57. Mineral, Lewis Co. Arsenic, quicksilver.
Station, T. E. R. R.
See also 27.

ANTIMONY DISTRICTS

See 15, 22, 32.

MOLYBDENUM DISTRICTS

See 7, 44, 47.

NICKEL DISTRICTS

See 39.

QUICKSILVER DISTRICTS

See 6, 57.

TIN DISTRICTS

58. Silver Hill, Spokane Co. Tin, tungsten.
Station, Spokane and Inland Empire Railroad. Pre-Cambrian gneiss
and schist cut by acidic and basic dikes and capped by basalt. Veins.

TUNGSTEN DISTRICTS

59. Deer Park, Stevens and Pend Oreille Cos. Tungsten.
5 miles N.E. Loon Lake, 10 miles N. Deer Park, G. N. Ry. Granite
and metamorphosed Paleozoic sediments. Lenses and veins.
See also 36, 58.

ZINC DISTRICTS

See 30, 43, 47, 50, 51.

INDEX OF MINING DISTRICTS AND CAMPS WITH THE COUNTIES IN WHICH THEY ARE LOCATED

The numbers refer to the preceding list of mining districts and to the accompanying map, which shows the location of the mining districts and camps

MINING DISTRICTS

Bald Mountain, Skagit	42	Monte Cristo, Snohomish	27
Barron (Slate Creek), Whatcom	31	Moses (Nespelem, Park City), Okanogan	19
Belcher, Ferry	37	Mount Baker, Whatcom	30
Blewett (Peshastin), Chelan	6	Myers Creek (Chesaw), Okanogan	19
Bridge Creek (Stehekin), Chelan	1	Nespelem (Moses, Park City), Okanogan	19
Bossburg, Stevens	49	Nighthawk, Okanogan	20
Carbon River, Pierce	41	Northport, Stevens	51
Cedar Canyon (Deer Trail), Stevens	36	Old Dominion (Colville), Stevens	52
Chesaw (Myers Creek), Okanogan	18	Orient, Stevens	29
Chewelah, Stevens	47	Oroville (Osyoos Lake), Okanogan	40
Columbia River, Ferry	12	Osyoos Lake (Oroville), Okanogan	40
Colville (Old Dominion), Stevens	52	Ozette River, Clallam	9
Conconully (Ruby), Okanogan	48	Palmer Mountain (Loomis, Wannacut Lake), Okanogan	21
Covada (Meteor), Ferry	32	Park City (Moses, Nespelem), Okanogan	19
Crystal, Lincoln	23	Pershall (Horseshoe Basin), Chelan	3
Danville, Ferry	13	Peshastin (Blewett), Chelan	6
Darrington, Snohomish	25	Railroad Creek, Chelan	7
Deep Creek Lake, Stevens	56	Republic (Eureka), Ferry	14
Deer Park, Stevens and Pend Oreille	59	Ruby (Conconully), Okanogan	48
Deer Trail (Cedar Canyon), Stevens	36	San Poil, Ferry	39
Entiat, Chelan	2	Shishi Beach, Clallam	10
Eureka (Republic), Ferry	14	Silver Creek, Snohomish	45
Fish Lake, Kittitas	16	Silver Hill, Spokane	58
Granite Falls, Snohomish	26	Silver Queen, Stevens	53
Hamilton, Skagit	55	Silverton (Stilaguamish), Snohomish	46
Horseshoe Basin (Pershall), Chelan	3	Slate Creek (Barron), Whatcom	31
Index, Snohomish	44	Snoqualmie Pass, King	54
Lakeside, Chelan	4	Squaw Creek (Methow), Okanogan	22
Leavenworth, Chelan	5	Stehekin (Bridge Creek), Chelan	1
Liberty (Swauk), Kittitas	17	St. Helens, Skamania and Lewis	43
Lone Star, Ferry	38	Stilaguamish (Silverton), Snohomish	46
Loomis (Palmer Mountain, Wannacut Lake), Okanogan	21	Swauk (Liberty), Kittitas	17
Metaline, Pend Oreille	50	Thunder Creek, Skagit	35
Meteor (Covada), Ferry	32	Twisp, Okanogan	23
Methow (Squaw Creek), Okanogan	22	Wannacut Lake (Palmer Mountain, Loomis), Okanogan	21
Methow, Upper, Okanogan	34	Wauconda, Okanogan	24
Meyers Falls, Stevens	28	Wenatchee, Chelan	8
Miller River (Money Creek), King	15	Yellow Banks, Clallam	11
Mineral, Lewis	57		
Money Creek (Miller River), King	15		

MINING CAMPS

Bald Mountain, Skamania	101	Idicle, Chelan	121
Berlin, King	102	Keller, Ferry	122
Black Hills, Thurston	103	Lake Cushman, Mason	123
Bruce Creek, Stevens	104	Little Dalles, Stevens	124
Buena Vista, King	105	Mt. Chopaka, Okanogan	125
Cascade, Skagit	106	Mt. Stuart, Chelan and Kittitas	126
Cedar River, King	107	Negro Creek, Chelan	127
Chloride, Okanogan	108	Ruby Creek, Whatcom	128
Chimacum, Jefferson	109	Ruth Creek, Whatcom	129
Clear Creek, Snohomish	110	Salmon Creek, King	130
Cle Elum, Kittitas	111	Salmon River, Okanogan	131
Clugston Creek, Stevens	112	Springdale, Stevens	132
Colville Reservation, Okanogan and Ferry	113	Storbo, Pierce	133
Doubtful Lake, Chelan	114	Sultan, Snohomish	134
Dutch Miller Gap, King	115	Summit, Pierce and Yakima	135
Flat Creek, Stevens	116	Summit, Stevens	136
Foss River, King	117	Valley, Stevens	137
Galena, Okanogan	118	White Horse, Snohomish	138
Goat Lake, Snohomish	119	Wolf's Camp, Ferry	139
Gold Creek, Kittitas	120		

Part III

BIBLIOGRAPHY OF ARTICLES RELATING TO MINING AND MINERAL RESOURCES IN THE STATE OF WASHINGTON

In the preparation of this bibliography it has been the aim of the writer to subdivide the work in such a way as to make the search for any desired article as easy as possible. To this end the bibliography has been divided into three major groups as follows:

- A. References to the State of Washington as a whole or to particular areas embracing more than one county;
- B. References to particular counties in their alphabetical order;
- C. References to metallurgical plants and processes.

The first two major groups have been further divided into sections having the following arrangement: (1) References of a general character; (2) References to particular metallic economic products, arranged alphabetically; (3) References to particular non-metallic economic products, also arranged alphabetically. The third major subdivision, metallurgical subjects, is divided by counties, alphabetically arranged.

Under the references to particular products, an effort has been made to group together all those occurring in any one publication and to arrange these chronologically, the publications themselves being placed in alphabetical order. In certain instances, however, many references to the same subject have been grouped together for convenience of reference.

PUBLICATIONS TO WHICH REFERENCE IS MADE AND ABBREVIATIONS USED IN THIS WORK

In beginning the search for references to be compiled in this bibliography, it was decided to examine only those publications which have a general interest, or an interest confined to the Pacific Northwest, as distinguished from those mining journals which are specifically devoted to other local interests, although containing frequently articles of general interest. It was further desired to use for search only such publications as are generally available in libraries. To these ends the following publications were carefully searched for such articles and references as were, in the judgment of the writer, of sufficient interest to warrant a place in a publication of the present character. Many of the articles listed are mere notes, containing little more than is indicated in the abstract which accompanies each reference; a sign (*) prefixed to any reference indicates that it is of this character. Articles from the maga-

zines and publications listed below are practically all derived from search by the writer. Articles listed from other publications have been taken from Bulletin No. 12, Washington Geological Survey, without further confirmation or scanning.

<i>Publication</i>	<i>Abbreviations.</i>
Alaska and Northwest Mining Journal.....	A. & N. W. M. J.
Bulletin of American Institute of Mining Engineers.....	Bull. A. I. M. E.
Engineering and Mining Journal.....	E. & M. J.
Mineral Industry.....	Min. Ind.
Mines and Minerals.....	M. & M.
Mining World.....	M. W.
Mining and Engineering World.....	M. & E. W.
Mining and Scientific Press.....	M. & S. P.
Northwest Mining Journal.....	N. W. M. J.
Northwest Mining News.....	N. W. M. N.
Pacific Mining Journal.....	P. M. J.
Transactions of American Institute of Mining Engineers.....	T. A. I. M. E.
United States Bureau of Mines, Bulletins.....	
United States Geological Survey, Annual Reports.....	
United States Geological Survey, Bulletins.....	U. S. G. S., Bull.
United States Geological Survey, Mineral Resources of the U. S.....	U. S. G. S., Min. Res. of U. S.
Washington Geological Survey, Annual Reports.....	
Washington Geological Survey, Bulletins.....	W. G. S., Bull.

Of the publications listed above, complete or nearly complete files were available for nearly all from 1890 to May 1, 1918, or from the beginning of publication to the latter date, or to the date of discontinuation.

Northwest Mining Journal was changed in 1912 to Pacific Mining Journal, and this in turn changed again with issue No. 3 of Vol. III to Alaska and Northwest Mining Journal, its present title. The available files of Northwest Mining Journal were incomplete. Beginning with Vol. II, No. 1, July, 1906, nearly all the issues to October, 1908, were searched, but subsequent to the latter date only a few numbers up to December, 1910, were available for scanning.

Northwest Mining News was changed to Northwest Mining and Metallurgy, beginning in May, 1913. The available files of this publication were only approximately complete, the numbers between May, 1911, and October, 1912, being missing, as were also a few other issues, and no numbers were available after June, 1913.

Mines and Minerals is of interest only between Vols. 19 and 33, inclusive, for which period it was published under the name here given. Before Vol. 19 it was known as the Colliery Engineer and Metal Miner, and after Vol. 33 as the Colliery Engineer, both devoted largely to coal mining. For that reason the only volumes searched were those indicated.

Mineral Industry, including the issue of 1916, and Mineral Resources, including the issue of 1915, and advance sheets of 1916, have also been searched, but the scanning of these publications is not complete to May 1, 1918.

Mining World, and Engineering and Mining World are continuous publications; the latter was absorbed by Engineering and Mining Journal in the early part of January, 1917.

During the years from 1890 to 1918 many county boundaries were changed. Some counties were subdivided, with the formation of new counties, while in other cases the names have been changed, as in the case of Chehalis County, now Grays Harbor County.

In the bibliography the references are classified according to the present names of the counties of the State, so far as the writer was able to determine the localities described.

SCHEME SHOWING ARRANGEMENT OF TITLES IN BIBLIOGRAPHY, PART III

A. References to the State of Washington as a whole or to particular areas embracing more than one county.

(1) References of a general character.

- a. Reviews of mining.
- b. Statistical information.
- c. References to particular portions of Washington, embracing more than one county.
- d. References to mineral resources of Washington.
- e. References of a miscellaneous nature.

(2) References to particular metallic economic products, arranged alphabetically.

(3) References to particular non-metallic economic products, also arranged alphabetically.

B. References to particular counties in their alphabetical order.

(1) References of a general character.

(2) References to particular metallic economic products, arranged alphabetically.

(3) References to particular non-metallic economic products, arranged alphabetically.

C. References to metallurgical plants and processes.

Arranged alphabetically by counties.

REFERENCES TO THE STATE OF WASHINGTON AS A WHOLE OR TO PARTICULAR AREAS EMBRACING MORE THAN ONE COUNTY

**Indicates a brief reference. Articles without title are listed by an abstract of their contents*

REVIEWS OF MINING

1. METALLIFEROUS MINING IN WASHINGTON. *Armstrong, L. K.*
M. & N. W. M. J., vol. 8, no. 3, March 1916, p. 50, 1¾ pp.
A review of metal mining in 1915.
2. MINING IN EASTERN WASHINGTON IN 1906. *Joseph, M. H.*
E. & M. J., vol. 83, no. 4, Jan. 26, 1907, p. 185.
Summary of operations and development.
3. A DESCRIPTION OF THE GENERAL GEOLOGY AND ORE DEPOSITS OF THE CASCADES. *Blackburn, C. F.*
M. & S. P., vol. 61, no. 20, Nov. 15, 1890, p. 317, ¼ column.
A prediction that immense mineral resources will be developed in the State.
4. WASHINGTON MINES. *Blackburn, C. F.*
M. & S. P., vol. 63, no. 14, Oct. 3, 1891, p. 213, ½ column.
An optimistic view of the mining future of the State.
5. MINING IN WASHINGTON.
M. & S. P., vol. 65, no. 20, Nov. 12, 1892, p. 317, ½ column.
6. MINING OUTLOOK IN WASHINGTON. *MacLeod, Taylor D.*
M. & S. P., vol. 65, no. 22, Nov. 26, 1892, p. 348, 1 column.
Resumé of operations.
7. IDAHO, OREGON AND WASHINGTON IN 1909. *Armstrong, L. K.*
M. & S. P., vol. 100, no. 1, Jan. 1, 1910, p. 19, 1½ columns devoted to Washington.
A resumé of mining operations in these states.
8. NEGLECT OF MINING IN THE CASCADES.
M. & S. P., vol. 101, no. 4, July 23, 1910, p. 124.
Special correspondence.
9. MINING IN THE NORTHWEST.
M. & S. P., vol. 102, no. 15, Apr. 15, 1911, p. 536.
General article by a correspondent.
10. MINING IN WASHINGTON IN 1911.
M. & S. P., vol. 104, no. 1, Jan. 6, 1912, p. 87, ½ column.
General review.
11. MINING IN WASHINGTON IN 1912.
M. & S. P., vol. 106, no. 1, Jan. 4, 1913, p. 82, 1 column.
General review.
12. THE MINING SITUATION IN WASHINGTON. *Rathbun, J. C.*
M. W., vol. 23, no. 20, Nov. 18, 1905, p. 556, 1¼ pages.
A general discussion of development with particular reference to the Mount Baker district in Whatcom County, Stevens and Snohomish counties, and the Olympic Peninsula. Discusses business opportunities in mining.

13. MINING DEVELOPMENT IN WASHINGTON. *Rathbun, J. C.*
M. W., vol. 24, no. 4, Jan. 27, 1906, p. 172, 2½ pages.
An account of the development by counties.
14. REVIEW OF MINING IN THE U. S. IN 1906. *Rathbun, J. C., and Joseph, M. H.*
M. W., vol. 26, no. 4, Jan. 26, 1907, p. 151, 3 pages.
A resumé of development in mining in eastern and western Washington.
15. REVIEW OF MINING IN THE U. S. IN 1911.
Washington, 2400 words.
M. & E. W., Jan. 27, 1912, p. 241.
NOTE.—In addition to the foregoing listed Reviews of Mining, reference may be had to the annual review numbers published very shortly after the beginning of each calendar year by the following magazines: E. & M. J., M. W., M. & E. W., M. & S. P., and M. & M. Similar reviews of mining development for certain products may also be found under the heading of the respective states in "Mineral resources of the United States," published annually by the United States Geological Survey, and in "Mineral Industry," an annual publication.

STATISTICAL INFORMATION

For statistical information of various kinds reference may be had to the special numbers of the various magazines and to the other reviews mentioned in the preceding note.

REFERENCES TO PARTICULAR PORTIONS OF WASHINGTON EMBRACING MORE THAN ONE COUNTY

16. EASTERN WASHINGTON AS A MINING SECTION. *Dewsnap, S. G.*
N. W. M. J., vol. 3, no. 4, Apr. 1907, p. 45.
A sketch of geological conditions in eastern Washington.
17. GEOLOGY OF WASHINGTON, WITH AN ATTEMPT TO CLASSIFY THE VEIN SYSTEM. *Ingalls, A. O.*
N. W. M. J., vol. 7, no. 5, June 1909, pp. 51-53.
Geological descriptions of the Cascade Range, Okanogan Mountains, Skagit Mountains, Okanogan Valley, Mounts Baker, Rainier, Aix, and Stuart, Glacier Peak, and the Columbia Lava Flow. Detailed description of the assumed vein system.
18. INTERNATIONAL GEOLOGY OF THE CASCADE REGION.
Evans, Horace F.
M. W., vol. 25, no. 9, Sept. 1, 1906, p. 236.
A resumé of the results of a geological reconnaissance of the northern Cascades.
19. TWO WASHINGTON MINING DISTRICTS. *Brinsmade, Robert B.*
M. & S. P., vol. 113, no. 21, Nov. 18, 1916, pp. 743-745.
Description of the Metaline and Bald Mountain districts in Pend Oreille and Skamania counties. Notes on certain properties.
20. MINING IN THE PACIFIC NORTHWEST. *Hodges, L. K.*
Published by the Seattle Post-Intelligencer, 1897, 192 pages.
Descriptions of the more important mines and prospects in the following districts:

Chelan County:	Icicle, Wenatchee, Peshastin, Negro Creek, Leavenworth, Lake Chelan, Stehekin.
King County:	Miller River, Money Creek, Snoqualmie, Buena Vista, Cedar River.
Kitsap County:	Chico tin mines.

Kittitas County:	Gold Creek, Swauk, Cle Elum.
Lewis County:	Mineral Creek.
Lewis, Cowlitz, and Skamania counties:	St. Helens.
Pierce and Yakima counties:	Summit.
Okanogan County:	Methow, Twisp, Salmon River, Okanogan Lake, Palmer Mountain, Colville Reservation.
Snohomish County:	Monte Cristo, Goat Lake, Silverton, Silver Creek, Index, White Horse.
Skagit County:	Skagit Copper Belt, Cascade, Thunder Creek.
Stevens County:	Northport, Colville, Cedar Canyon.
Whatcom County:	Slate Creek, Ruth Creek (Ruby Creek?).
Contains also a list of mines and claims in Washington.	

21. MINING AND METALLURGICAL JOURNEY, A.

N. W. M. N., vol. 7, no. 5, pp. 80-85, Aug. 1912.

Account of a trip made through the Colville Valley, passing Chewelah, Colville, Marcus, Orient, Laurier, and Republic; also includes geologic descriptions with extensive discussion of different methods used in handling ores.

22. MOTHER LODE IN THE CASCADE MOUNTAINS. *Ludloff, A. K.*

M. & S. P., vol. 73, Dec. 26, 1896, p. 521.

A brief description of the geology and ores of a portion of the Cascade Mountains north of Mount St. Helens.

23. MOUNT STUART FOLIO, No. 106, 1904, U. S. G. S. GEOLOGIC ATLAS. *Smith, Geo. Otis.*

Gold. Describes auriferous gravels of the Swauk and Peshastin districts and gold-quartz veins of the latter, with a description of the Warrior-General mine. Describes the Negro Creek district (mentions "Nickel Dikes") and the Swauk district, p. 9.

Copper and silver. Describes copper belt in the Negro Creek district with a note on the Grand View mine (copper), p. 9.

Nickel. "In the Negro Creek district (not as an ore). "Nickel Ledges." Quicksilver. "Deposits on middle fork Teanaway River."

24. NORTHERN CASCADES. *Evans, Horace F.*

M. & S. P., vol. 100, March 26, 1910, pp. 448-449.

Describes climate, occurrence of the rocks, geologic history, and nature of the copper deposits of the Osoyoos Basin.

24A NORTHWEST MINES HANDBOOK. *Norman, Sidney, et al.* SPOKANE, 1918.

A reference work of mining in the Northwest, including Idaho, British Columbia, Washington, Montana and Oregon. Gives the following information on the State of Washington:

Production of State from 1860.

Geology, by Prof. Chas. E. Weaver, University of Washington.

Resources, by Prof. Solon Shedd, Washington State College.

Geology of Chewelah District, by L. K. Armstrong, E. M.

Stevens County Magnesite, by Prof. F. W. Handy.

Chewelah District, Editorial, with Map and Key.

Electric Point District, Editorial.

Cedar Canyon District, Editorial.

List of over 300 Mines and Corporations, with Capital, Officials, Property, Development and Other Details.

Biographical Sketches of Leading Mining Men.

25. OLYMPIC COUNTRY. *Gilman, S. C.*

National Geographic Magazine, vol. 7, Apr. 1896, pp. 133-141.

Comprehensive article including paragraphs on location, age of Mount Olympus,, country rock, hot springs, iron, gold, timber and climate.

26. OLYMPIC NATIONAL PARK, THE PROPOSED. *Roberts, Milnor.*

M. & M., vol. 27, no. 9, April 1907, p. 398.

Brief description of some of the iron, manganese and copper deposits of the region.

27. OLYMPIC MOUNTAINS, WASHINGTON, NOTES ON SOME ROCKS FROM THE SAWTOOTH RANGE OF THE. *Arnold, Ralph.*

American Journal of Science, fourth series, vol. 28, July 1909, pp. 9-14.

A brief description of the general geology of the Sawtooth Range, with a description of the character, occurrence, and location of ores, sedimentary, metamorphosed sedimentary and igneous rocks.

28. OLYMPIC PENINSULA, MINERAL RESOURCES OF. *Reagan, Albert B.*

M. & E. W., vol. 35, Sept. 2, 1911, p. 425.

A summary of the known mineralogical resources of the field.

29. ORE DEPOSITS OF NORTHEASTERN WASHINGTON, THE. *Bancroft, Howland.* Including a section on the Republic mining district, by *Waldemar Lindgren and Howland Bancroft.*

U. S. G. S., Bulletin 550, 1914, 215 pages, illustrated.

A description of the ore deposits of Ferry, Stevens, and Pend Oreille counties, together with a small portion of Okanogan County. Describes history of mining activity, mining and metallurgical conditions, topography, geology and mineral deposits, and describes the following mining districts and properties:—

PEND OREILLE COUNTY

Metaline district: Oriole claim, lead, zinc, gold, silver; Clark group, zinc, lead; Lead King, lead, zinc; Cliff, lead, zinc; Schellenburg property, lead, zinc; Riverside property, lead, copper; Meade property, lead, copper.

STEVENS COUNTY

Northport district: Last chance property, lead, zinc; Treadwell group, lead; Scaman claim, lead; Anaconda claim, lead, zinc, copper; Copper King claim, lead, zinc, copper; Frisco-Standard group, lead, zinc, copper; Keough, lead, zinc, copper, gold; W. J. Bryan, lead; Sunset, lead, zinc, copper, gold, silver; Great Republic, copper, gold, silver; Double Standard, copper, gold, silver; Young America mine, lead, silver; Bonanza mine, lead, silver.

Orient district: First Thought mine, gold; Second Thought group, gold; North Star, gold; Globe group, copper; Scotia, copper; Copper Butte, copper; Orient; Defender group; Trojan; Big Iron, copper; Pomeroy, copper and lead; Easter Sunday, copper, gold, silver; McNally, copper; Kettle River group, lead, zinc, copper; Little Giant, lead, copper; Swamp King, gold; Beecher, lead, gold; McKinley group, gold; Napoleon mine, gold.

Chewelah district: United Copper mine, copper; Strobeck property; Delmonico (Enterprise), copper, lead, zinc, silver; Blue Star (Eagle), lead, silver, gold; Jay Gould, zinc, lead, copper; U. S. Copper Gold, copper, gold; Windfall, copper, arsenic; Copper Queen, copper; Hartford group, copper, silver, gold; Liberty, gold, silver, copper; Nevada, lead, zinc, silver.

Deer Trail (Cedar Canyon) district: Brooks, lead, silver; Sunday Morning, lead, silver; Little Frank, lead, silver; Hoodoo, lead, silver; Germania Camp, tungsten.

Other deposits: Columbia River Gold Mining Co., gold, copper; Silver Queen, silver, zinc, lead, copper; Old Dominion, lead, silver; Tungsten King, tungsten, bismuth.

FERRY COUNTY

Republic (Eureka) district: Southern Republic (Princess Maude), gold, silver; Chico, gold; Republic, gold, silver; Quilp, gold, silver; Blacktail, gold, silver; Surprise, Lone Pine, and Pearl, gold, silver; Insurgent, gold, silver; San Poll, gold, silver; Ben Huk, gold, silver; Trade Dollar, gold, silver; Knob Hill, gold, silver; Mountain Lion, gold, silver; Morning Glory, gold, silver; Tom Thumb, gold, silver.

Belcher district: Oversight group, copper, gold, silver, nickel (?), cobalt (?); Copper Key mine, copper, gold; Belcher, copper.

Sanpoll district: Congress claim, nickel, cobalt, silver; Manila mine, copper; Polepick, copper, zinc, lead.

Covada or Meteor (Enterprise) district: Meteor, copper, zinc, lead; Stray Dog, copper, zinc, lead, silver; Advance, copper, lead, zinc, silver; Keystone, lead, zinc, copper, silver; Longstreet, copper, zinc, lead, antimony; R. E. Lee, antimony; Silver Leaf, copper, zinc, lead, antimony.

Other deposits: Lone Star and Washington, copper; Hercules, copper; Surprise mine, gold; Lucile Dreyfuss mine, copper, gold; California mine, gold, silver; Iron Mountain prospect, silver, gold, lead, arsenic; Laurier prospect, copper; Jenny prospect, gold, silver, copper, lead.

OKANOGAN COUNTY

Park City district: Castle Creek prospects, lead, zinc, copper, silver; Ramore Mining Co. claim, lead, silver, copper, zinc; Wasco group, silver, copper, gold.

METALLURGY

Descriptions of mills on Kettle River claim, at Germania Camp, at Old Dominion mine, and at Republic mine.

30. PHYSICAL GEOGRAPHY AND GEOLOGY OF WASHINGTON.

Landes, Henry.

State Bureau of Statistics, Department of Agriculture and Immigration, pp. 43-74, Olympia, 1901.

Describes topography; gives general articles on Puget Sound, and the mineral resources of the State.

31. SNOQUALMIE FOLIO, No. 139, 1906, U. S. G. S. GEOLOGIC ATLAS OF THE U. S. *Smith, Geo. Otis, and Calkins, Frank Cathcart.*

Describes the following mineral resources of King and Kittitas counties:—
Iron. Describes magnetite deposits of Snoqualmie Pass (Denny and Guye prospects) and Cle Elum ores, p. 13.

Gold. Describes deposits at Camp Creek, Kittitas County, mentioning Maud O., Ida Elmore, Cle Elum, and Edna R. claims, p. 14.

*Mercury. On Boulder Creek, Kittitas Co., p. 14.

*Antimony. In Kittitas Co. on northern edge of quadrangle, p. 14.

Silver, gold, lead, and zinc. In Gold Creek district, Kittitas Co. Mentions Esther and Louisa claims and Cascade Mining Company's property, p. 14.

*Copper. On middle fork of Snoqualmie. Near Little Kachess Lake.

32. ST. HELENS MINING DISTRICT OF WASHINGTON, THE GEOLOGY OF. *Zapfee, Carl.*

Economic Geology, vol. 7, no. 4, 1912, pp. 340-350.

Includes location and extent, physiography, topography, lithology, structure, metamorphism, and economic geology of the region.

33. ST. HELENS MINING DISTRICT, THE. *Winchell, Horace V.*

T. A. I. M. E., vol. 44, 1912, p. 580.

A history of the district, with an account of its topography and geology. Estimate of the attractiveness of the district to experienced prospectors.

34. ST. HELENS MINING DISTRICT, THE. *Winchell, Horace V.*

NOTE—In addition to the foregoing articles referring to particular sections of the State, reference may also be had to the Mining Summaries and Mining News Departments of the E. & M. J. M., W. M. & E. W., M. & S. P., and M. & M. These departments appear in practically every number of these journals and note the current developments in the various counties or sections of the State, giving details of development progress, accounts of mineral discoveries, etc.

REFERENCES TO MINERAL RESOURCES OF WASHINGTON

35. GEOGRAPHY, DODGE'S ELEMENTARY. Rand, McNally & Co., 1904.

General article on the State, including mining, etc.

36. GEOGRAPHY OF WASHINGTON. Rand, McNally & Co., 1905.

Includes position and boundaries, mineral products, etc. Another edition was prepared for juvenile use. 1900.

37. METALLIFEROUS RESOURCES OF WASHINGTON EXCEPT IRON, THE.

Landes, Henry; Thyng, W. S.; Lyon, D. A., and Roberts, Milnor.

Washington Geological Survey, vol. 1, Annual report for 1901, pp. 39-136, pl. 6-9.

A brief resumé of the occurrences of metalliferous minerals in the State and detailed description of the properties listed below.

STEVENS COUNTY

Northport district: Bullion group, silver, lead, gold; Silver King group, lead, silver.

Myers Falls district: Mint group, gold, silver, copper; St. Paul-Express claim group, gold, silver, copper.

Flat Creek district: Examiner group, silver, gold.

Colville district: Bonanza mine, lead, silver.

Chewelah district: Minnehaha claim, gold, silver, copper; Blue Creek group, copper.

Springdale district: Kemp-Komar group, copper, gold, silver; Honest John, silver, lead.

Cedar Canyon district: Deer Trail mine, silver, lead, zinc, gold; Silver Queen mine, silver; Silver Seal Fraction, silver; Brook's group, silver; Orchid group, silver, lead.

FERRY COUNTY

Republic district: Mountain Lion mine, gold; Republic mine, gold; Tom Thumb mine, gold, silver; Quilp mine, gold, silver; Lone Pine-Surprise mine, gold, silver; Black Tail mine, gold, silver; San Poil mine, gold; Ben Hur mine, gold, silver; El Caliph mine, gold; Morning Glory mine, gold and silver tellurides; Princess Maud mine, silver, gold; Butte and Boston mine, gold, silver.

LINCOLN COUNTY

Crystal claim, silver and lead.

OKANOGAN COUNTY

Wauconda district; Wauconda group, gold.

Myers Creek district: Monterey claim, gold, silver, copper, lead; Yakima claim, copper, lead, zinc, gold, silver; Review group, gold, copper; The Mary Ann Creek Placers, gold.

Palmer Mountain district: Palmer Mountain group, gold, silver; Gold Hill mine, gold, silver; Golden Zone mine, gold, copper, lead, molybdenum; Bull Frog group, gold, silver; Black Bear and War Eagle, gold, silver, copper; Tribune group, gold, silver; Whisky Hill group, gold.

Conconully district: Q S group, gold, copper; Blue Lake group, gold, copper; Tough Nut mine, silver, lead; Homestake mines, silver, lead; Arlington mine, silver.

Moses district: Multnomah group, gold, silver, copper, lead; Apache claim, silver, gold; Great Western group, silver, lead.

Upper Methow district: Methow group, copper, silver; Oriental and Central claim, gold; Goat Creek group, copper, silver, gold.

Twisp district: Spokane claim, zinc, arsenic, copper; St. Lawrence group, gold, silver, copper.

Squaw Creek district: Hidden Treasure group, gold, silver, copper; Highland Light mine, gold, silver, copper; Standard and Louisa claims, gold, silver, copper; Henrietta group, gold, silver, copper; Hunter claim, gold, copper, silver; Tom Hal mine, gold, silver, copper; Bolinger group, gold, silver; Independence claim, gold, arsenic, copper, molybdenum.

WHATCOM COUNTY

Mount Baker district: Post Lambert mine, gold; Great Excelsior mine, gold, silver; Nooksack mine, gold; Terra Alta, gold; Saginaw group, copper, gold; Pierce group, gold; Lone Star group, gold.

Slate Creek district: Eureka mine, gold, silver; Mammoth mine, gold; Tacoma claim, gold; Gold Ridge group, gold; Ninety-Nine group, gold; Anacortes group, gold; North American group, gold; Monte Cristo claims, gold.

Thunder Creek district: Willis and Everett group, silver, gold; Lakeside claim, gold, silver; Great Northern claim, gold, silver, zinc.

Bald Mountain district: Bald Mountain mine, copper, gold.

CHELAN COUNTY

- Horseshoe Basin district: Black Warrior claim, lead, copper, silver; Davenport claim, lead, copper, silver, gold; Texas Jack claim, copper, silver.
- Bridge Creek district: Butte claim.
- Railroad Creek district: Crown Point mine, molybdenum; Holden group, copper, gold, silver.
- Peshastin district: Eureka mine, gold; Tip Top mine, gold; Lucky Queen mine, gold; Culver group, gold; Peshastin mine, gold; Olden mine, gold; Pole Pick mine, gold, silver, lead; Golden Eagle mine, gold; Ivanhoe mine, gold, silver; Black Jack mine, gold.

SNOHOMISH COUNTY

- Darrington district: Burns group; Blue Bird group; Elwell-Darrington group; Barley group, gold; Hunter and White Gander group; Molly group, gold, silver, copper; Sloman claim.
- Stilaguamish district: Forty-five mine, silver, gold, lead, zinc, copper, arsenic; Little Chief claim, gold, copper; Independent group, gold, arsenic; Imperial mine, copper, silver, gold; Bonanza Queen group, gold, copper, arsenic; St. Louis mine, copper, silver, gold; Helena group.
- Monte Cristo district: Monte Cristo mine, gold, arsenic; O. & B. mine, gold, silver, arsenic, lead, zinc.
- Silver Creek district: Bonanza group, gold, copper, arsenic; Copper Chief group, gold, silver, copper, lead, arsenic; Ontario group, lead, silver, gold.
- Index district: Ethel mine, copper; Sunset mine, copper; Copper Bell mine, copper, silver; Index group, copper; Index-Bornite group, copper, silver; Index Independent group, copper; Gunn's Peak group, copper, silver.

KING COUNTY

- Miller River district: Great Republic group, antimony, gold, silver; Mono group, copper, arsenic, gold, silver; Metropolitan claim, gold silver.
- Money Creek district: Apex mine, gold, silver, lead, arsenic.
- Salmon Creek district: Yellow Jacket group, gold; Climax group, copper, silver.
- Snoqualmie Pass district: Carmack group, gold, silver, lead.
- Dutch Miller district: Dutch Miller group, copper, gold.

KITITAS COUNTY

- Swauk district: Placer deposits.

PIERCE COUNTY

- Carbon River district: Surprise group, gold, copper; Clipper claim; Chicago group, copper, gold; East Lake group, copper; Blue Star group, copper, gold, silver; Tacoma group, copper, gold, silver.

LEWIS AND SKAMANIA COUNTIES

- St. Helens district: Sweden group, copper, gold, silver; Bronze Monarch group, gold, silver, copper; Norway group, gold, silver, copper; Young America group, gold, silver, copper; Chicago and Yellow Metals groups, gold, copper, silver; Samson group, gold, silver, copper; Index group; Polar Star mine, copper; Juanita claim, gold, copper; Washington claim; Ripper and Chief claims, gold, copper, lead.

METALLURGY

Includes also descriptions of the following reduction plants:

- Smelting works: Everett smelter; Tacoma smelter; Northport smelter.
- Chlorination and cyanidation plants: Republic mill (Republic dist.); Mountain Lion mill (Republic dist.).
- Stamp mills (Amalgamation): Blewett mill (Peshastin dist.); Eureka mill (Slate Creek dist.); Mammoth mill (Slate Creek dist.); Black Bear mill (Palmer Mountain dist.); Ivanhoe mill (Palmer Mountain dist.); Triune mill (Palmer Mountain dist.); Spokane mill (Palmer Mountain dist.); Mount Baker mill (Mount Baker dist.); Great Excelsior mill (Mount Baker dist.).
- Arrastres: Swauk Creek district: Peshastin district; Slate Creek district.
- Concentrators and combination plants: Wauconda mill (Wauconda dist.); Golden Zone concentrator (Palmer Mountain dist.); Ruby concentrator (Ruby dist.); Old Dominion concentrator (Colville dist.).

38. MINES AND MINERALS OF WASHINGTON. *Bethune, Geo. A.*

First Annual Report of State Geologist, 1891.

Describes Tacoma, Colville and Spokane smelters; gives history of early gold mining; describes the iron ores, and the following mining districts and properties:

OKANOGAN COUNTY

Ruby district: Arlington mine, gold, silver, copper; Fourth of July, silver, copper; First Thought; Ruby, gold, silver; War Eagle, silver; Idaho, gold, silver, lead.

Salmon River district: Lone Star, gold, silver, lead; Tough Nut, silver, lead, copper; Home Stake, silver, lead; Salmon River group, silver, lead; Lady of the Lake, gold, silver, lead; Laeuna, silver, copper; Hard-scrabble, silver; Sunrise, silver, copper; Grover Cleveland, silver, lead, copper; Mohawk, silver, lead, copper; Brunswick, silver, lead; Washington, silver, lead.

Galena mining district: silver, copper.

Wannacut Lake district: Black Bear mine, gold; War Eagle, gold; Golden Crown, gold; Ivanhoe, silver; Bunker Hill, gold; Triune, gold; Jessie, gold; Occident, gold.

Mount Chopaka district: Eureka group, lead; Julia, lead; Washington Mining Co., silver, lead; Caaba, silver, lead; Eagle, silver, lead.

Chloride district: Chloride claim, silver, copper; Windfall, silver.

Methow district: Red Shirt claim, gold, silver.

Osoyoos district: gold.

STEVENS COUNTY

Colville district: Old Dominion, silver, lead; Young America, silver, lead; Bonanza, silver, lead.

Summit district: Daisy, silver, lead; Wellington, silver, lead; Belle of the Mountain, gold; Old Abe, silver, copper; Victory, silver, lead; Tempest, silver, lead; Best Out, silver, lead; Lucky Jim, silver, lead.

Little Dalles district: Silver Crown, silver, lead; Excelsior, silver, lead.

Chewelah district: Eagle, silver, lead; Summit, silver, lead; Capital, iron; Finley, silver, lead.

Clugston Creek district: Tenderfoot, silver, lead; Silver-Lead claim, silver, lead.

Bruce Creek district: Alki group, silver, lead; Dead Medicine, silver, lead.

PEND OREILLE COUNTY

Metaline district, silver, lead.

SNOHOMISH COUNTY

Silver Creek district: Blue Bird, silver, lead; National, gold, silver; Jasper, silver, lead; Morning Star, silver, lead.

Monte Cristo district.

Sultan district: gold, silver.

Miscellaneous deposits: Skagit County near Hamilton, asbestos; Skagit County (Whatcom County?), Fairhaven, graphite; Okanogan County, Salmon River, molybdenum; Skagit and Spokane counties, mica; Stevens County, chrome iron; Clallam County, nickel.

38A. MINES AND MINERALS OF WASHINGTON. *Bethune, Geo. A.*

Second annual report of State Geologist, 1892.

Describes Washington coals; discusses iron deposits in general and those of Skagit, King and Kittitas counties in particular. Describes the following mining districts:

Okanogan County: Ruby, Salmon River, Wannacut Lake, Mount Chopaka, Chloride and Methow districts.

Chelan County: Lake Chelan and Peshastin districts.

Stevens County: Colville, Summit and Bruce Creek districts.

Pend Oreille County: Metaline district.

Kittitas County: Cle Elum and Swauk districts.

Skagit County: Cascade district.

Snohomish County: Monte Cristo, Silver Creek and Stilaguamish districts.

King County: Snoqualmie district.

Gives a general description of Washington places and mentions the formation of two new mining districts, Gold Hill in Yakima County and Mineral Creek in Lewis County. Notes the discovery of chrome-iron ore in Skagit and Kittitas counties.

39. MINES OF WASHINGTON. *Bethune, Geo. A.*
M. & S. P., vol. 62, no. 11, Mar. 14, 1891, p. 168.
Editorial review of the first annual report of State Geologist.
40. MINERAL POSSIBILITIES OF THE PACIFIC COAST, LATENT.
M. & S. P., vol. 91, no. 2, July 8, 1905, p. 22, 1½ columns in entire article.
Notes occurrence of molybdenum at Crown Point mines, Chelan County, and graphite near Bossburg, Stevens County.
41. MINERALS OF WASHINGTON. *Roberts, Milnor, and Mead, H. L.*
University of Washington Bulletin, Series no. 2, no. 25, pp. 40-48, January 1906.
Description of 16 of the most important minerals of the State, grouped under the headings of sulphides, oxides and silicates. A brief statement is given of the occurrences and uses of each mineral.
42. MINERAL INDUSTRY IN THE PACIFIC NORTHWEST, THE.
Roberts, Milnor.
E. & M. J., vol. 88, no. 5, July 31, 1909, p. 221.
Extract from address by the president before the Pacific Northwest Society of Engineers. Brief discussion of mineral resources of Washington.
43. MINERAL RESOURCES OF THE STATE OF WASHINGTON, THE. A Handbook treating the minerals of the State by districts and mineralogically.
N. W. M. J., special number, vol. 7, no. 5, August 1909.
Illustrated by numerous maps and halftones. A description of the following mining districts and properties:

PEND OREILLE COUNTY

Metaline district: Oriole mine, gold, silver, lead, copper; Mammoth mine, lead, silver; Morning mine, lead, silver.

STEVENS COUNTY

Chewelah district (L. K. Armstrong): United Copper, copper, silver; Liberty Copper Mining Co. claims, gold, copper, silver.
Cedar Canyon district: silver, copper, tungsten.
Orient district (L. K. Armstrong): First Thought mine, gold; Chima-cum group, gold; Valley Dew, gold; First Thought Extension, gold; Second Thought, gold; North Star, gold; Trophy, gold; Beecher group, gold; Chief and Butte group, copper, iron and gold; Easter Sunday, copper, gold, silver; Big Iron, iron; Napoleon mine, gold; Scotia, copper; Orient, copper; Defender group, gold, lead, silver; Trojan, lead, copper, gold; Blue Grass, iron, gold, copper; Paymaster; Butte and Washington, lead, silver; The Summit Gold and Copper Mining Co. property, gold, copper.

FERRY COUNTY

Republic district (J. L. Harper): Republic mine, gold, silver; Black Tail mine, gold, silver; Golden Eagle property, gold, silver; Tom Thumb, gold, silver; Mountain Lion, gold, silver; Knob Hill, gold, silver; Trade Dollar, gold, silver; Ben Hur, gold, silver; North San Poll, gold, silver; Lone Pine, gold, silver; Surprise, gold, silver; Quilp, gold, silver; Southern Republic, gold, silver.
Keller district: Manilla Copper mine, copper; Walla Walla Copper, copper, silver; Meadow Creek Copper and Molybdenite Co., copper, gold, silver, lead, molybdenum; Byrne property, silver, gold; Summit group, copper, silver; Silver King group, silver, lead, copper; Silver Hill group, copper, silver, gold; Gold Cord, silver, copper, gold; Silver Crown group, silver, lead, copper, nickel.
Belcher district (S. G. Dewsnap): Over-sight group, copper, gold; Copper Key group, copper, gold; Bortle group, copper, gold; Belcher, iron, copper; Winnipeg, gold, copper; Churchill group, silver, lead, iron; Iron Queen group.
Covada district (G. A. Mathews): Meteor mine, gold, silver; New York, silver; Montana, silver; Stray Dog, gold, silver; Keystone; Advance Mining Co. property; Buster mine; Longstreet and R. E. Lee claims, silver, antimony.

OKANOGAN AND FERRY COUNTIES

Park City district: Raymore group, copper, gold, silver; Park and Central group, lead, silver; Mountain Boy group, silver; Summit, silver.

OKANOGAN COUNTY

Nespelem district: Double Header group, gold, silver; San Marino Mining and Milling Co., gold, silver.

Palmer Mountain district: Prize mine, lead; Night Hawk mine, silver; Copper World Extension, copper, gold, silver; Lone Pine group, gold, silver; Pinnacle Gold Mine Co., gold.

Conconully district: Q. S. mines, copper, gold; Conconully Copper Co. mine, gold, silver, copper; Pennsylvania and Washington Co. mines, gold, silver, copper; Mineral Hill group, gold, silver, copper, molybdenum.

CHELAN COUNTY

The Lake Chelan Country (S. G. Dewsnap): Meadow Creek Camp, gold, copper, silver.

Chelan Butte district: gold.

The Railroad Creek district (O. Robert Dahl): Holden mine, gold, copper, Aurelia Crown group, gold, copper, silver, molybdenum; Croesus group, copper, silver, molybdenum.

Mount Stuart district (A. O. Ingalls): Copper, iron, mercury, also gold, cerium.

WHATCOM COUNTY

Mount Baker district (F. L. Otis): Post-Lambert mine, gold; Great Excelsior mine, gold; Mount Baker and Shuksan Mine Co., gold; Mount Baker Gold, Copper and Tin Co., (a) White Swan group, gold, silver, thallium, (b) Yellow Aster group, nickel, arsenic, gold, silver, copper; Copper Mountain group, gold, copper, lead, zinc, tin, molybdenum; U. S. Modern Mining Co., gold, silver, copper, zinc.

Slate Creek district: Chancellor group, gold; Beck group, gold; Eureka group, gold; Mill Creek mine, gold; North-American property, gold; Anacortes mine, gold; Seattle-St. Louis Mining Co., gold; The Walla Walla group, gold.

SKAGIT AND CHELAN COUNTIES

Cascade district: Everett Lode, silver; North Coast Mining and Milling Co.; Thunder Creek Mining Co., lead, silver, gold, copper, zinc, platinum, iridium, osmium; Cascade Consolidated Mining and Smelting Co., gold, silver, lead.

SNOHOMISH COUNTY

Silverton (Stillaguamish) district (O. Robert Dahl): Independent, gold, silver; Cleveland group, gold, silver, copper; Anacortes Lode, gold, arsenic, lead; Big Four group, lead, silver, arsenic; Forty-five group, silver, gold, lead, zinc, copper, arsenic; Cascade group, gold, silver, lead, copper; Bonanza Queen, gold, silver, copper; Eclipse group, gold, silver, arsenic, antimony.

Monte Cristo district (A. O. Ingalls): Peabody group (76 group), gold, silver, lead, arsenic.

Darrington district, gold, silver, copper.

Silver Creek district: Mineral Mountain Mining and Tunnel Co., gold, silver, copper, arsenic; Vandalia mine, lead, silver, gold; Edison group, gold, copper; Good Hope Gold and Copper Mining Co., gold, silver, copper, lead, arsenic.

Index district: Index Bornite, copper, silver; Gunn's Peak mine, copper, silver; Sunset Copper mine, copper; Nonpareil Consolidated, copper; Trout Creek mine, copper; Kittanning Copper mine, copper; Ethel Consolidated, copper, gold, silver; Bunker Hill Mining and Smelting Co.

KITITITAS COUNTY

Gold Creek district: Devine group, copper, silver, gold.

KING COUNTY

Miller River district: Snoqualmie mine, copper, lead, silver, gold; Cleopatra, silver, antimony; Coney, gold, silver, lead; Portland, copper; Una mine, copper; Seattle Cascade Mining Co., lead, copper, gold, silver; Mono mine, copper; Apex, gold, arsenic.

Foss River district (A. W. McIntire): Foss River Consolidated Copper Co., copper, gold, silver.

Also a review of the mineral resources of the State considered separately under the headings of the following minerals, with descriptions of their locations:

Copper; gold; zinc; silver; iron (A. O. Ingalls); arsenic (Harold Howes); antimony; lead; molybdenum (A. O. Ingalls); rare ores (A. O. Ingalls); (tungsten; strontium; rare earths; arsenic) bismuth; nickel; tantalum; tin; gem stones.

44. MINERAL RESOURCES OF WASHINGTON, THE, WITH STATISTICS FOR 1912. *Landes, Henry.*

W. G. S., Bull. 11, 1914.

A report on the mineral resources of Washington, including descriptions of granite quarries, sandstone quarries, lime kilns, basalt quarries, sand and gravel pits, coal mines, clay plants, cement plants, metal mining (including a list of the metal mines then in operation) and mineral waters. Contains a map of Washington showing locations of mines, quarries, etc.

45. MINERAL POSSIBILITIES OF THE NORTHWEST. *Benson, H. K.*

M. & E. W., vol. 43, Nov. 13, 1915, p. 768.

A brief abstract from an address before the American Chemical Society (Seattle meeting) in which mineral possibilities were enumerated.

46. MINERAL WEALTH OF WASHINGTON. *Wolf, August.*

Pacific Monthly, vol. 19, pp. 474-477.

General article naming the chief minerals, ores and rocks, with their location and accessibility.

47. ORES, COALS, AND USEFUL ROCKS OF WASHINGTON; COLLEGE OF MINES SERIES OF. *Roberts, Milnor, et al.*

Bulletin of University of Washington, General Series, No. 110, University Extension Series, no. 21, 1917. 96 pages.

Notes non-metalliferous resources and rocks. Gives chapter on the ores and minerals of Washington, giving location of occurrences of antimony, molybdenum, lead, zinc, copper, arsenic, iron, and manganese, under the headings of the various minerals of these metals.

48. OUR PACIFIC NORTHWEST. *Darton, Nelson Horatio.*

National Geographic Magazine, vol. 20, pp. 645-663, July 1909. Illustrated. Maps.

General description of the State, including climate and scenery, with lists of principal resources.

49. PACIFIC SLOPE, RESOURCES OF THE. *Browne, J. Ross.*

New York, Appleton, 1869, pp. 537-576.

Gives mineral resources of State.

50. RESOURCES OF CALIFORNIA, WITH APPENDIX ON WASHINGTON TERRITORY. *Hittell, J. S.*

San Francisco, Bancroft, 1882.

Includes size, location, and descriptions of the principal cities, Columbia River, Puget Sound, the lakes and rivers, Mount Rainier, rocks, mining and products of Washington.

51. ROCK SPECIMENS FROM THE STATE OF WASHINGTON, THE SCHOOL OF MINES SERIES OF. *Roberts, Milnor, et al.*

Bulletin of University of Washington, series 2, no. 25, 40 pages. January 1906.

Brief descriptions of the rocks and minerals of the State, including gravels, sands, clays, sandstones, shales, concretions, limestone, diatomaceous earth, coal, peat, lignite, granite, tuff, andesite, basalt, marble, slate, schist, dolomite, and serpentine.

52. SOME RECENT MINERAL DISCOVERIES IN THE STATE OF WASHINGTON. *Ruffner, W. H.*

Science, vol. 19, p. 58, 1892.

Discusses the following mining districts with brief topographic and geologic description; Cascade, Silver Creek, and Monte Cristo.

53. **USEFUL MINERALS OF THE UNITED STATES.** *Schrader, Frank C., Stone, Ralph W., and Sanford, Samuel.*
U. S. G. S., Bull. 624, 1917, p. 326.
Describes the useful minerals (metallic and non-metallic) listed by states. Gives also their approximate location.
54. **WASHINGTON TERRITORIAL RESOURCES.** *Evans, Elwood.*
Olympia, 1877.
Brief political history. . . . Geology, mineralogy, with descriptions of the Columbia River, Columbia plain, Colville country, Yakima valley, Puget Sound, Grays Harbor, Shoalwater Bay, and rivers emptying into the Sound. Brief descriptions of each county.
55. **WASHINGTON, RESOURCES AND FUTURE OF.** *Clifford, H. B.*
Address in Boston, published by the Northern Syndicate, Jan. 14, 1890.
Brief political history, and general remarks on commerce, . . . coal, iron, precious metals, and cities.
56. **WASHINGTON MINES.**
N. W. M. N., vol. 2, no. 5, April 1908, p. 99.
A description of some of the mineral deposits of the State.
57. **WASHINGTON'S MINERAL RESOURCES. METALS.** *Roberts, Milnor.*
Manufacturing opportunities in the State of Washington, chap. xvii, pp. 148-156. Dept. of State, Olympia, Wash., 1918.
A description of the conditions of mining in the State, with a statement of the principal minerals mined, the minor minerals, the iron ores, and the total mineral production. Also outlines the research to be undertaken in aid of the mineral industry, gives the sources of information regarding minerals in Washington and states the advantages to manufacturing due to the mineral resources of the State and adjacent regions.
58. **WESTERN EMPIRE, OUR.** *Brockett, L. P.*
San Francisco, 1881, p. 1189-1213.
Lists minerals, gives location and extent of coal fields, etc.
59. **WHERE WASHINGTON STANDS AS A MINERAL STATE.** *Stratton, D. F.*
Washington Magazine, vol. 1, pp. 161-164, October-November, 1906.
Gives principal ores of chief ore-bearing counties with brief geologic history of their formation.

REFERENCES OF A MISCELLANEOUS NATURE

60. **ALASKA-YUKON-PACIFIC EXPOSITION.** *Herrick, R. L.*
M. & M., vol. 30, no. 2, Sept. 1909, p. 99, 6 pp. illustrated.
A description of the grounds, buildings and mining exhibits.
61. **BOUNDARY DISTRICT, ETC.**
M. & S. P., vol. 95, no. 17, Oct. 26, 1907, p. 513.
*A map of the Boundary district and northern Washington and Idaho showing mining districts.
62. **MINING ADVANCE INTO THE INLAND EMPIRE, THE**
Trimble, William J.
A thesis submitted for the degree of Doctor of Philosophy at the University of Wisconsin, 1914.
A comparative study of the beginnings of the mining industry in Idaho and Montana, eastern Washington, and Oregon, and the southern interior of British Columbia; and of institutions and laws based upon that industry.
63. **MINING DISTRICTS OF THE WESTERN UNITED STATES.**
Hill, James M. With a geologic introduction by *Waldemar Lindgren.*
U. S. G. S., Bull. 507, 1912, pp 41-42, 279-288.

Includes local geology of ore deposits and extensive classification of mining districts of the State. Also references under each district to publications descriptive of the district.

64. MINING AND METALLURGICAL EXPERIMENT STATION OF THE U. S. BUREAU OF MINES, AT SEATTLE, AN ACCOUNT OF THE OPENING OF THE.

M. & S. P., vol. 114, no. 5, Feb. 3, 1917.

A description of the nature of the work to be undertaken at this station.

65. NEW NORTHWEST STATION OF THE BUREAU OF MINES

Roberts, Milnor.

M. & E. W., vol. 45, no. 26, Dec. 23, 1916, p. 1075. Illustrated.

Account of the installation of the new station at Seattle, and of the work to be undertaken.

66. RETRACEMENT OF THE BOUNDARY LINES BETWEEN IDAHO AND WASHINGTON. *Marshall, R. B.*

U. S. G. S., Bull. 466, 1911. 39 pp.

67. SEATTLE ASSAY OFFICE, THE. *Lyon, D. A.*

M. & M., vol. 21, no. 6, Jan. 1901, p. 245, 1 column.

An account of the installation and equipment of the Government office.

See also 24A.

REFERENCES TO PARTICULAR ECONOMIC PRODUCTS

ARSENIC

68. U. S. G. S., MIN. RES. OF U. S., 1914, PT. I.

Brief mention of deposits at Monte Cristo, pp. 954 and 957; Skagit County, p. 957; Skagit County (Clark Lake), p. 959; Covada, p. 957; Mineral, Lewis County, p. 959; Production notes, p. 960.

See also 43.

BISMUTH

See also 43.

COPPER

69. COPPER DEPOSITS OF WASHINGTON. *McIntire, A. W.*

Address before the American Mining Congress, Ninth Annual Session. Report of proceedings, pp. 238-250, 1907.

See the following references for details of this address.

70. COPPER DEPOSITS OF WASHINGTON. *McIntire, A. W.*

N. W. M. J., vol. 2, no. 6, Dec. 1906, p. 79, 4½ pp., illustrated.

(A reprint of the address noted under the preceding reference).

Discussion of the gold ore deposits of the Monte Cristo district and the effect of J. A. Spurr's report on mining in Washington. Discusses water power features and describes the following mines: Apex, King County; Dutch Miller Gap properties, King County; Foss River group, King County; Copper Bell, Snohomish County; Bonanza Queen, Snohomish County; Polar Star, Skamania and Cowlitz Counties; Belcher mine, Stevens County; Copper World Extension, Okanogan County; Q. S., Okanogan County.

71. COPPER MINES OF THE U. S. IN 1905, THE. *Weed, Walter Harvey.*

U. S. G. S., Bull. 285, 1906, p. 123.

Gives copper production, lists mines, and describes occurrences of the ore. Notes on Copper King mines, Stevens County; First Thought, Orient, Belcher mines, Ferry County, and Index deposits.

See also 43, 79, 84, 85, 86, 88, 99.

GOLD

72. GOLD ORES OF WASHINGTON AND OREGON. *Lincoln, Francis Church.*
E. & M. J., vol. 92, no. 1, July 1, 1911, p. 13.
A review of the geologic conditions in the Republic and Monte Cristo districts and the North Pole Shear Zone in Oregon, which have furnished most of the gold produced by these States.
73. *GENERAL DESCRIPTION OF UPPER COLUMBIA RIVER PLACERS.
M. & S. P., vol. 67, no. 7, Aug. 12, 1893, p. 110.
- 73A. BLACK SANDS OF THE PACIFIC SLOPE, USEFUL MINERALS IN THE.
Day, David T. and Richards, R. H.
U. S. G. S., Min. Res. of U. S. for 1905, pp. 1175-1258. Washington, D. C., 1906.
Full description of an investigation of the black sands found in the rivers on the Pacific slope and in the ocean beaches. Contents: Introduction, previous investigations of black sand, preliminary work of present investigation, field examination, minerals found, methods of concentration, methods of testing sands, schemes for examination of black sand, results of concentration, costs of concentration, electric smelting of magnetite from black sands, papers bearing on black sands.
74. BLACK SANDS OF THE PACIFIC SLOPE.
M. & S. P., vol. 92, no. 10, March 10, 1906, p. 157, 2 columns.
The minerals and their treatment at the Portland experimental plant.
75. BLACK SANDS OF THE PACIFIC COAST. *Lang, Herbert.*
M. & S. P., vol. 113, no. 23, Dec. 2, 1916, 3 pp.
A discussion of the occurrence and treatment of these deposits.
76. THE PACIFIC COAST BEACH SANDS.
M. & M., vol. 30, no. 6, Jan. 1910, p. 375, 1¼ pp.
Description of deposits of Pacific Coast and their economic importance.
77. BLACK SANDS OF THE PACIFIC COAST, THE. *Day, David T.*
M. W., vol. 27, Nov. 16, 1907, p. 891; Nov. 30, p. 974; Dec. 7, 1907, p. 1013.
A statement of the black sand problem in its relation to gold mining, and a discussion of the economic products to be derived from the sand.
Note of the tests conducted at the Portland exposition.
78. BEACH SAND, MINING, PACIFIC COAST. *Stovall, Dennis H.*
M. W., vol. 28, June 13, 1908, p. 938.
A brief account of the black sand deposits of the Pacific Coast beaches.
79. WASHINGTON GOLD.
Science, new series, vol. 19, May 27, 1904, p. 839.
Short article on occurrences of gold, copper, nickel, and coal with estimate as to their development.
80. GOLD PRODUCTION OF NORTH AMERICA, GEOLOGICAL FEATURES OF THE. *Lindgren, Waldemar.*
T. A. I. M. E., vol. 33, 1903, pp. 790-845.
Gives brief statistics of output, geological features, distribution and future tendency of State.
81. GOLD PLACERS ON THE COAST OF WASHINGTON. *Arnold, Ralph.*
U. S. G. S., Bull. 260, 1905, pp. 154-157.
History of mining carried on between Cape Flattery and Grays Harbor; also gives character of sand from which the gold is derived, mentioning methods used to best advantage. Describes Shishi Beach placers near Point of Arches; Ozette placer, 2 mi. north of the Ozette River mouth; and Yellow Bank placers, 6 mi. south of Ozette River.

82. GOLD-BEARING RIVER SANDS OF NORTHEASTERN WASHINGTON.

Collier, Arthur J.

U. S. G. S., Bull. 315, 1907, pp. 56-70.

Description of . . . relation of gold deposits to terraces; minerals associated with gold, typical conditions and localities of occurrences; Nespelem Bar, Hell Gate Bar, benches near Peach, Six-mile Cr., Nine-mile Cr., Wilnot Bar, Roger's Bar, Blue Bar, and San Poil Valley.

83. NOTES ON MINING CONDITIONS AND PROGRESS IN WASHINGTON.

U. S. G. S., Min. Res. of U. S., 1892, p. 84, 1 p.

Production of gold and silver by years from 1880-1892.

84. GOLD, SILVER, COPPER, AND LEAD. *Yale, Chas. G.*

U. S. G. S., Min. Res. of U. S., 1903, pp. 194-196; 1904, p. 217; 1905, pp. 331-337; 1906, pp. 362-368; 1907, pp. 468-477 (Part I); 1908, pp. 573-582 (Part I); 1909, pp. 485-491 (Part I).

A resume of the production of these metals by counties in 1903, 1904, 1905, 1906, 1907, 1908, 1909.

85. GOLD, SILVER, COPPER, LEAD, AND ZINC. *Gerry, G. N.*

U. S. G. S., Min. Res. of U. S., 1910, pp. 597-605 (Part I); 1911, pp. 778-788 (Part I).

A resume of the production of these metals by counties in 1910 and 1911.

86. GOLD, SILVER, COPPER, AND LEAD. *Gerry, G. N.*

U. S. G. S., Min. Res. of U. S., 1912, pp. 914-923 (Part I); 1913, pp. 789-801 (Part I); 1914, pp. 641-654 (Part I).

A resume of the production of these metals by counties in 1912, 1913, 1914.

87. GOLD AND SILVER.

U. S. G. S., Min. Res. of U. S., 1914, p. 846 (Part I).

Lists output as largely from Ferry and Stevens Counties.

88. GOLD, SILVER, COPPER, LEAD, AND ZINC. *Gerry, G. N.*

U. S. G. S., Min. Res. of U. S., pp. 561-575 (Part I).

A resume of the production of these metals by counties in 1915.

See also 43

IRON

89. THE ELECTROCHEMICAL POSSIBILITIES OF THE PACIFIC COAST STATES AS COMPARED WITH THOSE OF SWEDEN AND NORWAY.

Beckman, J. W.

Metallurgical & Chemical Engineering, July 1, 1916.

90. WASHINGTON IRON.

M. & S. P., vol. 63, no. 15, Oct. 10, 1891, p. 234.

Editorial on the subject of the abundant deposits said to exist in the state.

91. *RESUME OF THE RESULTS OF THE INVESTIGATION OF IRON RESOURCES OF THE STATE FOR THE BUREAU OF INDUSTRIAL RESEARCH OF THE UNIVERSITY OF WASHINGTON.

M. & S. P., vol. 114, no. 6, Feb. 10, 1917, p. 211.

92. IRON AND STEEL ON THE PACIFIC COAST, OUTLOOK FOR.

Hersam, Ernest A.

M. & S. P., vol. 115, no. 4, July 28, 1917, p. 117, 6 pp.

A comprehensive article on the subject of the iron and steel situation on the Pacific Coast. Notes on the fuel resources of the coast, etc.

93. STEEL ON THE PACIFIC COAST.

M. & S. P., vol. 115, no. 4, July 28, 1917, p. 112, 2 columns.

An editorial on the possibilities of manufacture of steel on the Pacific Coast, including Washington.

94. BEACH SANDS OF THE PACIFIC COAST. *Mallery, J. L.*
N. W. M. J., vol. 5, no. 5, May 1908, p. 75, 2 pp.
Notes on their economic treatment and value as a source of iron.
95. IRON ORES OF THE UNITED STATES. *Eckel, E. C.*
U. S. G. S., Bull. 260, pp. 317-320.
96. TONNAGE OF PACIFIC COAST IRON DEPOSITS. *Hayes, C. W.*
U. S. G. S., Min. Res. of U. S., 1908, pp. 120-121.
97. AN INVESTIGATION OF THE IRON ORE RESOURCES OF THE NORTH-WEST. *Whittier, William Harrison*, Research Fellow.
University of Washington, Bureau of Industrial Research, 1917, Bull. No. 2, 128 pp.
Gives a history of the iron and steel industry in the Pacific Northwest; a discussion of the utilization of the iron ores in the Northwest, and a description of the iron ore deposits of the Northwest and Alaska. Gives estimate of tonnage of these resources; analyses of iron ores of the Pacific Coast; a description of metallurgical experiments on some of these ores; a discussion of coke, fluxes, and labor; gives costs of production and markets and draws conclusions as to the results of investigations. Bibliography and map. Describes the following deposits in Washington:

KITTITAS COUNTY

Cle Elum district.

KING COUNTY

Snoqualmie Pass district: Denny prospect; Guye prospect.

SKAGIT COUNTY

Hamilton district.

STEVENS COUNTY

Colville and Valley districts.

FERRY COUNTY

Belcher district: Copper Key claim.

MISCELLANEOUS DEPOSITS

Lake Cushman district, Mason County; Black Hills district, Grays Harbor County; Chimacum district, Jefferson County.

98. THE IRON ORES OF WASHINGTON. *Shedd, Solon.*
W. G. S., vol. 1, Annual Report for 1901, Part IV, pp. 1-40, pl. 18-21.
A description of the iron ores, their relative value, a brief history of their mining, distribution, character and commercial value. Describes conditions in Skagit, Kittitas, King, Stevens and Mason counties. Gives analyses of ores from the Lake Cushman district, Black Hills district (Grays Harbor County), and Hamilton district (Skagit County). Describes in detail the occurrences of the ores at Hamilton, Snoqualmie Pass, Cle Elum, in the Colville and Valley districts (Stevens County), and the Clugston Creek district (Stevens County).
See also 43, 73A, 74, 75, 76, 77, 78.

LEAD

See 84, 85, 86, 88.

MOLYBDENUM

99. MOLYBDENUM, ITS ORES AND THEIR CONCENTRATION.
Horton, Frederick W.
U. S. Bureau of Mines, Bull. 111.
Description of deposit in quartz at Crown Point mine, Chelan County. Development work. Illustrated. pp. 79-83.
Description of large, low-grade deposit in granite, 10 miles from Tonasket, near Loomis, Okanogan County, on Aeneas Mn., p. 83, ½ p.

Robischaud mine on the northeast side of Lake Chelan at head of Safety Harbor Creek. Description of deposit associated with chalcopyrite. p. 84, $\frac{1}{2}$ p.

Description of deposit on Sheep Mountain in northern part of Okanogan County, 1 mi. south of Monument no. 11, U. S.-Canada boundary line. In pegmatite. p. 84, $\frac{1}{2}$ p.

*Description of deposit near Oroville, Okanogan County, on east slope of hills, west of Lake Osoyoos at 49th parallel, Golden Chariot and O. K. prospects, associated with chalcopyrite. p. 85.

*Also near Conconully, Okanogan County; near Skykomish, King County; in the Monte Cristo district in Snohomish County; on the north side of Mt. Rainier, near the White River Glacier, Pierce County; on Thunder Creek, tributary to Skagit River; in San Poil district, Ferry County; and Metaline district, Pend Oreille County.

See also 43.

NICKEL

100. *AN ABSTRACT FROM BANCROFT'S REPORT ON THE ORE DEPOSITS IN NORTHEASTERN WASHINGTON.

U. S. G. S., Min. Res. of U. S., 1915, p. 757 (Part I).

See also 43, 79.

PLATINUM

101. PLATINUM IN THE UNITED STATES *Day, David T.*

M. & S. P., vol. 100, no. 17, Apr. 23, 1910, p. 582.

Mentions west coast of Washington.

NOTE. This article refers to another article by Dr. Day in "Science"

A search of this magazine from 1905 to 1910 failed to show the presence of any article by Dr. Day on platinum.

SILVER

See 43, 83, 84, 85, 86, 87, 88.

TANTALUM

TIN

See 43.

TUNGSTEN

See 43.

ZINC

102. ZINC ORES IN WASHINGTON.

A. & N. W. M. J., vol. 7, no. 4, October 1915, p. 74, 1 $\frac{1}{2}$ pp.

An extract from Bancroft's report on the ore deposits of northeastern Washington. (U. S. G. S., Bull. 550.)

See also 43, 85, 88.

STRONTIUM

103. NOTE ON A DEPOSIT OF WORKABLE SIZE IN WASHINGTON.

U. S. G. S., Bull. 666 W.

Deposit of celestite. Locality not specified. (Possibly Fidalgo Island.)

See also 43.

ARTICLES PERTAINING TO PARTICULAR COUNTIES

The counties are listed in alphabetical order. Under each county the articles are grouped in the following order: References of a general character; References to particular metallic economic products, arranged alphabetically; References to particular non-metallic economic products, also arranged alphabetically.

CHELAN COUNTY

Articles of a general character

104. LAKE CHELAN DISTRICT. *Lakes, Arthur W.*
M. & M., vol. 20, no. 6, Jan. 1900, p. 268, 2 pp.
Description of topography and geological history of the region.
105. LAKE CHELAN COUNTRY, THE BEAUTIFUL. *Dewsnap, S. G.*
N. W. M. J., vol. 5, no. 5, May 1908, p. 77, 2 pp.
A description of the lake and some of the mineral resources of the surrounding country.
106. DOUBTFUL LAKE DISTRICT, WASHINGTON.
P. M. J., vol. 1, no. 3, Sept. 1912, p. 7, $\frac{1}{2}$ p.
Lead, copper, gold, and silver. A description of the geology, vein system, and development of the camp near the summit of the Cascade Mountains in Chelan County. Describes property of the Cascade Consolidated Mining and Smelting Company.
107. BLEWETT MINING DISTRICT, GEOLOGY AND ORE DEPOSITS OF.
Weaver, Charles E.
W. G. S., Bull. 6, 1912.
Gives history of mining, ore treatment, description of ore bodies, genesis of ores, and detailed description of the following mines:— Washington Meteor, Alta Vista, Pole Pick No. 1, Blinn, North Star, Golden Eagle, Tip Top, Wilder, Golden Guinea, Lucky Queen, Blue Bell, Prospect, Homestake, Lone Rock, and Johnson.
108. ABSTRACT OF THE ABOVE.
M. & E. W., vol. 35, Sept. 16, 1911, p. 529.
See also 20, 23, 37, 43, 52.

Aluminum

109. *DEPOSIT NEAR MERRITT.
A. & N. W. M. J., vol. 9, no. 2, Aug. 1916, p. 55.

Cobalt

See 136.

Copper

110. *LOW-GRADE DEPOSIT CARRYING GOLD AT HOLDEN PROPERTY, RAILROAD CREEK.
M. & S. P., vol. 94, no. 2, Jan. 12, 1907, p. 41.
See also 23, 37, 43, 99, 106, 132, 135, 136, 142.

Gold

111. *MEADOW CREEK MINES, SOUTHWEST (northeast?) OF LAKE CHELAN.
M. & S. P., vol. 65, no. 12, Sept. 17, 1892, p. 198.
112. *PLACERS ON WENATCHEE RIVER, JUST BELOW MOUTH OF PESHASTIN CREEK.
M. & S. P., vol. 68, no. 15, Apr. 14, 1894, p. 238.
113. *IN PARTIALLY DECOMPOSED QUARTZ, TWO MILES FROM WENATCHEE.
M. & S. P., vol. 68, no. 24, June 16, 1894, p. 382.

114. *IN BLACK SAND PLACERS ON CHEWAWAH CREEK.
M. & S. P., vol. 70, no. 17, Apr. 27, 1895, p. 267.
115. *LARGE BODY OF FREE-MILLING QUARTZ OF GOOD GRADE AT CHELAN FALLS.
M. & S. P., vol. 77, no. 13, Sept. 24, 1898, p. 311.
116. *HORSESHOE BASIN MINING AND DEVELOPMENT CO. GOLD, SILVER AND LEAD. 25 MILES FROM THE HEAD OF LAKE CHELAN. (STEHEKIN DISTRICT.)
M. & S. P., vol. 86, no. 20, May 16, 1903, p. 324.
117. *WENATCHEE GOLD MINING CO. 6 MILES FROM ENTIAT.
M. & S. P., vol. 92, no. 7, Feb. 17, 1906, p. 115.
118. *GOLD-QUARTZ ON CHELAN BUTTE.
M. & S. P., vol. 94, no. 19, May 11, 1907, p. 584.
119. *ON CHELAN BUTTE, FREE GOLD VEIN FOUR FEET WIDE, FOUR INCHES OF WHICH IS HIGH GRADE.
M. & S. P., vol. 94, no. 26, June 29, 1907, p. 807.
120. *DESCRIPTION OF DEVELOPMENT OF THE WASHINGTON METEOR MINING CO. AT BLEWETT.
M. & S. P., vol. 97, no. 16, Oct. 17, 1908, p. 517.
121. *LOW-GRADE, FREE-MILLING ORE AT WENATCHEE MINE. 2½ MILES FROM WENATCHEE.
M. & S. P., vol. 101, no. 2, July 9, 1910, p. 63.
122. *GOLD IN QUARTZ AND SERPENTINE. FINE AND FLAKY. GOLDEN EAGLE MINING CO.
M. & S. P., vol. 107, no. 23, Dec. 6, 1913, p. 909.
123. *DISCOVERED ON THE CHEWAHWAH RIVER, 35 MILES FROM LEAVENWORTH.
E. & M. J., vol. 56, no. 13, Sept. 23, 1893, p. 328.
124. *RICH ORE IN REX MINE OF WENATCHEE GOLD MINING CO., ENTIAT VALLEY.
E. & M. J., vol. 95, no. 11, Mar. 15, 1913, p. 592.
See also 23, 37, 43, 106, 110, 116, 132.

Iron

125. *MAGNETIC IRON ORE AT BLEWETT, ON THE PROPERTY OF THE WASHINGTON STEEL & IRON CO. OF SPOKANE.
M. & S. P., vol. 101, no. 15, Oct. 8, 1910, p. 489.
See also 43.

Lead

126. LEAD AND SILVER.

*Notes on the deposits of galena, carrying silver, 50 to 200 ounces per ton in Horseshoe Basin.

M. & S. P., vol. 70, no. 20, May 18, 1895, p. 319.

See also 37, 43, 106, 116, 142.

Molybdenum

127. *NOTES ON DEVELOPMENT AT CROWN POINT MINE.

U. S. G. S., Min. Res. of U. S., 1901, p. 266.

128. *NOTES ON THE PRODUCTION OF MOLYBDENUM FROM THE CROWN POINT MINE.

U. S. G. S., Min. Res. of U. S., 1902, p. 287.

129. DESCRIPTION OF THE DEPOSIT AT CROWN POINT MINE.

U. S. G. S., Min. Res. of U. S., 1904, p. 340, ½ p.

130. NOTES ON AURELIA CROWN MINES WEST OF LAKE CHELAN.

U. S. G. S., Min. Res. of U. S., 1914, p. 925 (Part I).

131. MOLYBDENITE AT CROWN POINT, WASHINGTON. *Crook, A. R.*

Geological Society of America, Bull., vol. 15, pp. 283-288, 1904.

Includes occurrences, petrographical relationships, accompanying minerals, form of deposits, location of Crown Point mine, analysis of ore, character, paragenesis, associated minerals, and source.

132. CROWN POINT MINE. AT THE HEAD OF RAILROAD CREEK.

*Molybdenum, gold, copper, and vanadium.

M. & S. P., vol. 90, no. 8, Feb. 25, 1905, p. 125.

133. DESCRIPTION OF OCCURRENCE AT CROWN POINT MINE.

M. & S. P., vol. 91, no. 13, Sept. 23, 1905, p. 216, 200 words.

See also 37, 40, 43, 99.

Nickel

134. NICKEL AND PLATINUM.

E. & M. J., vol. 59, no. 8, Feb. 23, 1895, p. 184.

Brief description of nickel lode on Negro Creek (Nigger Creek). 14 miles south of Peshastin. Platinum in creek bed.

135. NICKEL AND COPPER.

M. & S. P., vol. 70, no. 26, June 29, 1895, p. 415.

*Rainier mine on Negro Creek (Nigger Creek) near Leavenworth. Large ore bodies.

136. NICKEL, COBALT, AND COPPER.

M. & S. P., vol. 70, no. 25, June 22, 1895, p. 399.

*Ontario and Black Republican mines, near Leavenworth.

137. *ON RED BUTTE MOUNTAIN, NEAR INGALLS CREEK, NEAR MT. STUART.

M. & S. P., vol. 71, no. 5, Aug. 3, 1895, p. 79.

See also 23.

Platinum

138. *ON MAD RIVER, 25 MILES NORTH OF LEAVENWORTH. PLACER DEPOSIT.

M. & S. P., vol. 77, no. 25, Dec. 17, 1898, p. 613.

See also 134.

Quicksilver

139. NOTE ON "LEAVENWORTH PROSPECT."

U. S. G. S., Min. Res. of U. S., 1914, p. 329 (Part I).

140. *CINNABAR ON SQUAW SADDLE MOUNTAIN, 3 MILES FROM WEN-ATCHEE.

M. & S. P., vol. 106, no. 21, May 24, 1913, p. 797.

141. *CINNABAR DISCOVERED NEAR ORONDO.

*Note on the Kittitas County deposit.

U. S. G. S., Min. Res. of U. S., 1911, p. 916 (Part I).

See also 23, 43.

Silver

142. *SILVER, LEAD, AND COPPER (MOST OF IT CARBONATE).

M. & S. P., vol. 94, no. 9, March 2, 1907, p. 264.

Stehekin district. Leaching plant planned.

See also 23, 37, 43, 106, 111, 116, 126.

Tin

143. *DISCOVERED ON PESHAISTIN CREEK, NEAR THE BASE OF MOUNT STUART.

E. & M. J., vol. 52, no. 19, Nov. 7, 1891, p. 541.

Four to eight per cent tin.

144. *ON CHELAN BUTTE.

M. & S. P., vol. 99, no. 23, Dec. 4, 1909, p. 773.

Vanadium

See 132.

Cerium

See 43.

Graphite

145. *NOTE OF A DEPOSIT NEAR NASON.

U. S. G. S., Min. Res. of U. S., 1915, p. 93 (Part II).

146. *IN CHELAN COUNTY.

U. S. G. S., Min. Res. of U. S., 1916, p. 59 (Part II)

Mica

147. *NEAR CHELAN FALLS, 1½ MILES FROM THE TOWN.

E. & M. J., vol. 64, no. 10, Sept. 4, 1897, p. 289.

Good quality, but small sheets.

148. *ON MAD RIVER, NORTH AMERICAN ORE CO.

E. & M. J., vol. 96, no. 8, Aug. 23, 1913, p. 380.

149. *DEPOSIT ON MAD RIVER, NORTH AMERICAN ORE CO.

A. & N. W. J., vol. 3, no. 3, Sept. 1913, p. 59.

CLALLAM COUNTY

Gold

150. *PLACER GOLD DISCOVERED NEAR PORT ANGELES.
M. & S. P., vol. 61, no. 97, Aug. 16, 1890, p. 107.
151. *DISCOVERED IN BEACH SANDS, 4 MILES EAST OF PORT ANGELES.
M. & S. P., vol. 73, no. 4, July 25, 1896, p. 74.
152. *PLACER GOLD MINING ON THE BEACH.
M. & S. P., vol. 91, no. 3, 1905, p. 51.
Gold occurs in Pleistocene sands and gravels, accompanied by platinum and iridosmine. Associated with magnetite, garnet sand, and pyrite.
See also 81.

Iridosmine

See 152.

Iron

See 152.

Nickel

See 38.

Platinum

See 152.

CLARK COUNTY

Copper

153. WASHINGTON MINE.
M. & S. P., vol. 105, no. 25, Dec. 21, 1912, p. 811.
*Sixty inch lode carrying copper, gold, and silver; 100 ton mill, water power drive.

Gold

See 153.

Platinum

154. *REPORTED FROM THE SOUTH FORK OF LEWIS RIVER.
U. S. G. S., Min. Res. of U. S., 1915, p. 144 (Part I).
U. S. G. S., Min. Res. of U. S., 1916, p. 11 (Part I).

Silver

See 153.

COWLITZ COUNTY

Articles of a general character

See 20.

Copper

155. *"COPPER DYKE" PROPERTY.
M. & S. P., vol. 85, no. 2, July 12, 1902, p. 29.
Ore 2 per cent copper, gold \$1.00.
See also 70.

Gold

156. *QUARTZ LEDGES DISCOVERED IN TOWN OF KALAMA.
M. & S. P., vol. 82, no. 13, March 30, 1901, p. 162.
157. *NOTE OF A SIX-FOOT LEDGE OF QUARTZ CARRYING GOLD AND CINNABAR (Red Star Mining Co.).
M. & S. P., vol. 85, no. 2, July 12, 1902, p. 29.
158. *PLACER GOLD AT HORSESHOE FALLS.
E. & M. J., vol. 95, no. 15, Apr. 12, 1913, p. 780.
See also 155.

Quicksilver

See 157.

DOUGLAS COUNTY

Gold

159. GOLD.
E. & M. J., vol. 92, no. 13, Sept. 23, 1911, p. 614.
*Placers near Gordon, Douglas County; also contains small rubies.

Mica

160. *AT MINE OF SPOKANE MICA CO., NEAR TROY.
M. & S. P., vol. 94, no. 7, Feb. 16, 1907, p. 201.

Rubies

See 159.

FERRY COUNTY

Articles of a general character

161. *A VAST MINERALIZED BELT.
N. W. M. N., vol. 1, no. 7, June 1907, p. 29.
An account of the resources of the Colville Indian reservation.
162. EASTERN WASHINGTON AS A MINING SECTION. *Dewsnap, S. G.*
N. W. M. J., vol. 4, no. 1, July 1907, p. 3, 2 pp., maps.
Belcher Mountain mining camp. Describes geology of district and ore bodies of the following properties:— Oversight, Copper Key, Bortlie, Belcher, Winnipeg, Churchill.
Describes also transportation and smelter facilities.
163. COVADA MINING DISTRICT, GEOLOGY AND ORE DEPOSITS OF THE.
Weaver, Charles E.
W. G. S., Bull. 16, 1912.
Describes structural and economic geology and ore deposits of this district which contains galena, stibnite, sphalerite, molybdenite, silver, sylvanite, pyrrargyrite, and gold. Genesis of ores. Gives also detailed description of the following mines and prospects:— Advance Mining Co., gold, silver, lead, zinc; Mayflower claim, lead, gold, silver; Lakeview Fraction, gold, silver; Plymouth Rock claim, lead, silver, gold; Pilgrim claim, gold, silver; Bluebird claim, gold, silver; Quandary claim; King Solomon claim, gold, silver; Greasy Run claim, gold, silver; Silver Plume claim, lead; White Tail claim, lead, silver, gold; Black Tail claim, lead, silver, gold; Butterfly claim, gold, silver; Sunshine claim, silver; I. X. L. claim, gold, silver; Sunset claim, gold, silver; Old Nell claim, gold, silver; Polaris claim, gold, silver; Big Joker claim, lead; Kentucky Bell claim; Three Pines claim, lead; Silver Dollar claim; Summit claim, antimony, lead; Silver Crown No. 3

claim, gold, silver; Silver Crown No. 2 claim, gold, silver; Silver Crown No. 1 claim, antimony; Idora claim, lead; Ohio claim, lead; Drummond claim, lead, zinc, gold, silver; Chance claim, gold, silver; Royal Ann No. 1 claim, lead, gold, silver, zinc; Royal Ann No. 2 claim; Royal Ann No. 3 claim, gold, silver, lead; Reliance claim, gold, silver; Silver Flume claim; Silver Spar claim; Legal Tender claim, lead, zinc; Lone Pine claim; Big Bug claim, gold, silver; Colorado No. 1 claim; Colorado No. 2 claim, antimony, lead, gold, silver; Black Hawk claim, lead, zinc, antimony, gold, silver; Joker claim; Discovery claim; Little Jay claim, gold, silver; Cherokee Strip claim, gold, silver; Northern Lake claim, gold, silver; Shoo Fly claim, lead; Robert E. Lee claim, antimony, gold, silver; Longstreet claim, antimony; King Fraction claim, lead; Oom Paul claim, lead; St. Patrick claim, lead, gold, silver; Etta claim, lead, silver, gold; Several Fractions claim, lead; Silver Spar claim; Good Ore claim; Several claim, gold, silver; Blackhorn claim, gold, silver; Keystone claim, lead, zinc, copper; Syndicate claim; Dan Patch claim, gold, silver, lead, zinc; Ren Rice claim, gold, silver; Great Scott claim, gold, silver; Victor claim, gold, silver; Saint Paul claim, gold, silver; Jay Bird claim; Saint Paul claim, lead; Laurel claim; Rattler claim, gold, silver; Algonkian claim, gold, silver; Stray Dog claim, lead, zinc, silver; Imperial claim; Captain claim; White Rose claim; Dixie Queen claim; Reserve claim, lead, gold, silver; Ruby claim; Santa Claus claim; Neglected claim, lead, silver; Montana claim; Admiral claim; Snowstorm claim, gold, silver; Truax claim; Dead Shot claim; Juliet claim, antimony, gold, silver; New York claim, lead, silver; Red Chief claim, lead; Vernie claim, lead, zinc; Grand View claim, lead, silver; Laura S. claim, lead, silver; Dewey claim, silver; Syracuse claim, gold, silver; Perry claim, antimony; Silver Leaf claim, lead, zinc; Buffalo claim, gold, silver; Rosario claim; Guin mine, lead, gold, silver; Big Chief group of six claims; Meteor group of four claims.

164. COVADA DISTRICT GEOLOGY AND MINERAL DEPOSITS.

M. & S. P., vol. 107, no. 14, Oct. 4, 1913, p. 548, ½ column.

Abstract from above Bull. 16, W. G. S.

165. COVADA DISTRICT, OPERATIONS IN THE.

M. W., vol. 33, Aug. 27, 1910, p. 367.

A description and map of the properties of the district.

166. GEOLOGY AND ORE DEPOSITS OF REPUBLIC MINING DISTRICT.

Umpleby, Jos. B.

W. G. S., Bull. 1, 1910, 67 pp., 13 plates, 5 figures.

Gives location and physiography of the district; general geology, including descriptions of rocky formation in Paleozoic series, granodiorites, Tertiary formation, Quaternary history and economic geology. Gives map of the claims of the district. Describes metallurgical problems, history and production, ore deposits and development of the district. Describes in detail the following properties:— New Republic mine, Ben Hur mine, Morning Glory mine, South Republic mine, Quilp mine, Surprise mine, Black Tail mine, Lone Pine mine, San Poil mine, Mountain Lion mine, Tom Thumb mine, El Caliph mine.

167. GEOLOGY AND ORE DEPOSITS OF THE REPUBLIC DISTRICT.

Journal of Geology, vol. 19, p. 93.

A review of Umpleby's report bearing the same title.

168. GEOLOGY AND ORE DEPOSITS OF THE REPUBLIC DISTRICT.

Ransome, F. L.

Economic Geology, vol. 6, p. 412.

A review of Umpleby's report bearing the same title.

169. REPUBLIC DISTRICT.

E. & M. J., vol. 64, no. 19, Nov. 6, 1897, p. 559, 1 column.

Description of the ore bodies of the Eureka district.

170. REPUBLIC MINING CAMP. *Joseph, M. H.*

E. & M. J., vol. 68, pp. 635-636.

An account of the opening of the first mines, their output, and quality of the ore.

171. REPUBLIC MINE, WASHINGTON. *Joseph, M. H.*
E. & M. J., vol. 68, pp. 725-726.
Statistics of the owning company, output, value, description of vein, geology, and mine tunnel.
172. REPUBLIC, THE MOUNTAIN LION MINE AT. *Joseph, M. H.*
E. & M. J., vol. 69, March 10, 1900, p. 285.
A brief history and description of underground workings and mill plant.
173. REPUBLIC, WASHINGTON. *Joseph, M. H.*
E. & M. J., vol. 69, May 26, 1900, p. 617.
The Lone Pine Surprise Consolidated mines. An account of the ore bodies and development work.
174. REPUBLIC DISTRICT, WASHINGTON, THE.
E. & M. J., vol. 72, July 13, 1901, p. 37.
An account of the closing down of the principal mines and reduction works.
175. REPUBLIC DISTRICT, WASHINGTON, NOTES ON THE. *Ralston, J. C.*
E. & M. J., vol. 72, July 19, 1901, p. 74.
A discussion of the mineralogy and metallurgy of the ores and an account of the mill.
176. REPUBLIC DISTRICT, WASHINGTON, DEVELOPMENT OF.
Norman, Sidney.
M. & E. W., vol. 37, July 6, 1912, p. 12.
A summary of the history of the district, a description of the mills and of some of the properties, and of the need of cheap power for the camp.
177. REPUBLIC MINING CAMP, WASHINGTON, THE. *Joseph, M. H.*
M. & S. P., vol. 68, no. 22, Nov. 25, 1899, p. 635, 2 pp.
A resume of the progress of mining in the camp. Describes transportation, topography, geology, and ores.
178. REPUBLIC DISTRICT, WASHINGTON, THE.
M. & S. P., vol. 79, Sept. 16, 1899, p. 312.
A description of the district mills, and of development work.
179. MINES IN THE REPUBLIC DISTRICT, WASHINGTON. *Scott, W. A.*
M. & S. P., vol. 101, no. 7, Aug. 13, 1910, p. 200, illustrated, 2 pp.
Brief description of the various properties.
180. REPUBLIC MINING DISTRICT. *Joseph, M. H.*
M. & S. P., vol. 102, May 13, 1911, p. 667.
Brief discussion of a portion of Jos. B. Umpleby's report, W. G. S., Bull. 1, 1910.
181. REPUBLIC MINING DISTRICT. *Umpleby, Jos. B.*
M. & S. P., vol. 102, June 10, 1911, p. 792.
A reply to M. H. Joseph's discussion of Mr. Umpleby's report on W. G. S., Bull. 1, as discussed in the M. & S. P., vol. 102, May 13, 1911, p. 667.
182. REPUBLIC DISTRICT, WASHINGTON, MINES OF THE.
Norman, Sidney.
M. & S. P., vol. 105, August 24, 1912, p. 235.
A description of the expected "resurrection" of the camp.
183. REPUBLIC DISTRICT, MINING AND MILLING IN.
M. & S. P., vol. 107, no. 7, Aug. 16, 1913, p. 278, 1½ columns.
Development and mill construction in Chewelah, Northport, and Orient districts.

184. SOME PECULIAR ORE DEPOSITS. *Balfour, A. M.*
 M. & S. P., vol. 112, no. 21, May 20, 1916, p. 738, 2 columns.
 A brief discussion of some peculiarities of the ores of the Republic district.
185. REPUBLIC MINING DISTRICT, GEOLOGY AND ORE DEPOSITS OF.
Umpleby, Joseph B.
 N. W. M. N., vol. 6, no. 6, January 1911, p. 140.
 (From Bull. 1, W. G. S.)
 See also 21, 29, 37, 43.

Antimony

186. *STIBNITE IN A PORPHYRY DIKE ON R. E. LEE CLAIM, ENTERPRISE DISTRICT.
 M. & S. P., vol. 97, no. 21, Nov. 21, 1908, p. 686.
187. *IN THE ORE OF LONGSTREET MINE NEAR HUNTERS, ENTERPRISE DISTRICT.
 M. & S. P., vol. 98, no. 19, May 8, 1909, p. 647.
 Antimony eight per cent, gold, silver.
 See also 29, 43, 163, 198, 205.

Arsenic

188. *IN ORE IN THE PIN MONEY SHAFT, OVERSIGHT GROUP.
 M. & S. P., vol. 94, no. 9, Mar. 2, 1907, p. 264.
 See also 29, 68, 194.

Cobalt

189. *IN COMMERCIAL QUANTITY ON PROPERTY OF OVERSIGHT MINING AND MILLING CO., AT BASE OF MISSOURI MOUNTAIN, WITH GOLD.
 M. & S. P., vol. 93, no. 11, Sept. 15, 1906, p. 313.
190. *AS SMALTITE NODULES IN THE PIN MONEY CLAIM, OVERSIGHT GROUP.
 M. & S. P., vol. 93, no. 24, Dec. 15, 1906, p. 711.
 See also 29.

Copper

See 29, 43, 71, 195, 204.

Gold

191. REPUBLIC GOLD MINE, WASHINGTON, AN EXAMINATION OF.
Chatard, T. M., and Whitehead, Cabell.
 T. A. I. M. E., vol. 30, 1900, p. 419.
 An account of experiments in ore treatment by cyanide.
192. *RICH DISCOVERY ON THE COLVILLE RESERVATION.
 M. & S. P., vol. 61, no. 5, August 2, 1890, p. 71.
193. *PLACER CLAIMS ON MARY ANN CREEK.
 M. & S. P., vol. 86, no. 1, Jan. 3, 1903, p. 15.
194. MALACHITE GROUP NEAR KELLER.
 M. & S. P., vol. 88, no. 4, Jan. 23, 1904, p. 70.
 •Arsenical iron carrying gold.

195. LAKE GROUP MINERAL CLAIMS, SIX MILES SOUTH OF ORIENT.
M. & S. P., vol. 97, no. 1, July 4, 1908, p. 9.
*Gold-copper ore in iron-sulphide vein.
196. *PLACER GOLD, VALUE FROM 50 TO 75 CENTS PER CUBIC YARD
ON RICO PLACER GROUND, GOLD CREEK, 20 MILES SOUTH
OF REPUBLIC.
M. & S. P., vol. 102, no. 11, Mar. 18, 1911, p. 417.
See also 29, 37, 43, 72, 82, 87, 163, 166, 187, 189, 204.

Iron

197. *IRON MINES IN WOLF'S CAMP, COLVILLE RESERVATION.
M. & S. P., vol. 87, no. 1, July 4, 1903, p. 13.
Hematite, $1\frac{1}{2}$ miles from Curlew Lake.
See also 43, 97.

Lead

198. MOUNTAIN BOY MINE, NEAR REPUBLIC.
M. & S. P., vol. 94, no. 1, Jan. 5, 1907, p. 11.
*Galena and antimonial silver.
199. U. S. G. S., MIN. RES. OF U. S., 1914, p. 812 (PART I).
Lists two lead plants at Keller and Northport, but makes no mention of
any deposits.
See also 29, 43, 163, 204.

Molybdenum

See 43, 99.

Nickel

200. NICKEL DEPOSIT IN THE SAN POIL MINING DISTRICT, WASHINGTON.
Bancroft, H.
M. & S. P., Jan. 20, 1912, p. 144, 1800 words.
A description of the development, geology, and ore deposits of the Con-
gress mine, on Bridge Creek.
See also 29, 43.

Selenium

201. SELENIUM MINERAL IN THE GOLD-QUARTZ ORES OF THE REPUBLIC
DISTRICT. DISCOVERY OF SELENIUM.
Science, new series, vol. 30, p. 972, Dec. 31, 1909.
202. SELENIUM IN WASHINGTON.
M. & S. P., vol. 100, no. 6, Feb. 5, 1910, p. 224, $\frac{1}{2}$ column.
Description of ores in the Republic district containing about one per
cent selenium.

Silver

203. *HIGH-GRADE SILVER ORE, 35 MILES SOUTHWEST OF MYERS FALLS,
30 MILES WEST OF COLVILLE. NEAR RATTLESNAKE BUTTE.
M. & S. P., vol. 87, no. 11, Sept. 12, 1903, p. 176.
204. RAMORE MINE. PARK CITY, FERRY COUNTY.
M. & S. P., vol. 90, no. 4, Jan. 21, 1905, p. 46.
*Silver, lead, gold, copper.

205. *SILVER LEAF GROUP, ENTERPRISE DISTRICT.

M. & S. P., vol. 106, no. 15, Apr. 12, 1913, p. 557.

Sulph-antimonate silver ore (Ruby silver and stibnite).

See also 29, 37, 43, 163, 187, 198, 205.

Tungsten

206. *WOLFRAMITE, NEAR KELLER, AT HEAD OF COPPER CREEK.

M. & S. P., vol. 93, no. 17, Oct. 27, 1906, p. 501.

207. *SCHEELITE OF HIGH GRADE REPORTED IN THE SILVER LEAF MINE,

1½ MILES WEST OF THE COLUMBIA RIVER, TROY DISTRICT.

M. & S. P., vol. 112, no. 9, Feb. 26, 1916, p. 325.

Zinc

See 29, 163.

FRANKLIN COUNTY

Gold

208. *GOLD IN BLACK SANDS AT PASCO.

M. & S. P., vol. 88, no. 12, Mar. 19, 1904, p. 204.

Plant for extraction to be put up.

209. *AT RICHLAND, 8 MILES NORTH OF PASCO.

M. & S. P., vol. 91, no. 18, Oct. 28, 1905, p. 300.

Iron

See 208.

GARFIELD COUNTY

Lead

210. *GALENA, NEAR POMEROY. CARRIES SILVER.

M. & S. P., vol. 92, no. 5, Feb. 3, 1906, p. 78.

Silver

See 210.

GRANT COUNTY

Borax

211. *DEPOSIT 1½ MILES BY ½ MILE IN EXTENT, AND 8½ FEET THICK,
65 MILES EAST OF ELLENSBURG.

E. & M. J., vol., 53, no. 14, Apr. 2, 1892, p. 387.

Probably the sodium sulphate deposit mentioned in the succeeding reference.

Sodium sulphate

212. *LARGE DEPOSIT, 8 FEET THICK, DISCOVERED 40 MILES SOUTHWEST
OF WILBUR. AT FIRST THOUGHT TO BE BORAX.

E. & M. J., vol. 52, no. 26, Dec. 26, 1891, p. 734.

GRAYS HARBOR COUNTY

Gold

213. *PLACER DEPOSIT DISCOVERED ON WISHKAH RIVER, RUNNING INTO GRAYS HARBOR.
E. & M. J., vol. 56, no. 27, Dec. 30, 1893, p. 674.
214. *DEPOSITS OF BLACK SAND AT OCEAN BEACH, WILLAPA HARBOR.
M. & S. P., vol. 91, no. 22, Nov. 25, 1905, p. 371.

Iron

215. *MAGNETITE SANDS AT DAMON'S POINT, NORTH SIDE ENTRANCE TO GRAY'S HARBOR. IRON PRODUCTS PROPOSED.
M. & S. P., vol. 88, no. 4, Jan. 23, 1904, p. 70.
216. *SHAW CRUCIBLE STEEL CO., DAMON.
M. & S. P., vol. 92, no. 5, Feb. 3, 1906, p. 78.
See also 97, 98, 214.

Manganese

217. *DISCOVERED 25 MILES FROM ABERDEEN IN OLYMPIC FOREST.
M. & S. P., vol. 111, no. 22, Nov. 27, 1915, p. 637.
218. *NOTE OF A DEPOSIT IN THE OLYMPIC MOUNTAINS. LOCATION INDEFINITE.
U. S. G. S., Bull. 427, p. 159.
219. *MANGANESE OF GOOD GRADE REPORTED NEAR HUMPTULIPS.
U. S. G. S., Min. Res. of U. S., 1915, p. 41 (Part I).

JEFFERSON COUNTY

Copper

220. *DISCOVERY 22 MILES FROM PORT TOWNSEND.
M. & S. P., vol. 61, no. 17, Oct. 25, 1890, p. 269.
See also 221, 226, 227.

Gold

221. *GOLD-QUARTZ LODS ON DOSEWALLIPS RIVER, 19 MILES FROM HOODS CANAL, ASSOCIATED WITH PYRITE AND PEACOCK COPPER.
E. & M. J., vol. 64, no. 9, Aug. 28, 1897, p. 259.
222. *RICH GOLD-QUARTZ ON DOCEWALLIPS RIVER.
M. & S. P., vol. 84, no. 3, Jan. 18, 1902, p. 41.
223. *GOLD-BEARING BLACK SANDS, DISCOVERED NEAR FORT FLAGLER.
M. & S. P., vol. 84, no. 4, Jan. 25, 1902, p. 55.
See also 226, 227.

Iron

224. IRON MAKING AT PORT TOWNSEND. *Clapp, A. W.*

E. & M. J., vol. 73, Jan. 25, 1902, p. 137.

A description of the rehabilitation of the Irondale plant.

See also 97, 223, 226.

Manganese

225. MANGANESE IN THE OLYMPIC PENINSULA. *Dewsnap, S. G.*

E. & M. J., vol. 1, no. 4, Oct. 1912, p. 62, 2 pp. map.

A description of the geology, topography, and character of the ore bodies of the manganiferous belt near Hoods Canal.

226. MANGANESE AND IRON.

M. & S. P., vol. 99, no. 11, Sept. 11, 1909, p. 345.

*Tubal Cain Copper and Manganese Mining Co. Mine on Iron Mountain, 40 miles from Port Townsend in Olympic Mountains. Copper glance, chalcopryite, native copper, some gold and silver.

227. MANGANESE, COPPER, GOLD.

M. & S. P., vol. 107, no. 13, Sept. 27, 1913, p. 511.

*South of Mt. Constance. Vein 5 feet wide, 4 per cent copper.

Silver

See 226.

KING COUNTY

Articles of a general character

228. PETROLOGY AND ECONOMIC GEOLOGY OF THE SKYKOMISH BASIN, WASHINGTON. *Smith, Warren S.*

Columbia School of Mines quarterly, vol. 36, 1914-15, pp. 154-185.

Describes petrology and economic geology of the Basin. History of mining district, nature of ores, types of deposits and treatment problems. Description of Cleopatra mine; antimonial silver and galena; Coney mine, lead, zinc; Portland claim; Little Una claim; Dawson's claim, silver, lead; Seattle Cascade claim, lead, zinc, arsenic; Mono group, copper, zinc; Grand Central claim. All in the Berlin mining district.

See also 20, 31, 37, 43.

Antimony

See 37, 43, 228, 230.

Arsenic

See 37, 43, 228.

Copper

229. *DISCOVERED AT DUTCH MILLER GAP, KING AND KITTITAS COUNTIES

E. & M. J., vol. 62, no. 24, Dec. 12, 1896, p. 567.

230. *GREY COPPER AND ANTIMONIAL SILVER IN CLEOPATRA MINE ON MILLER RIVER.

E. & M. J., vol. 66, no. 9, Aug. 27, 1898, p. 260.

231. *HORSESHOE MINING CO.

M. & S. P., vol. 98, no. 20, May 15, 1909, p. 680.

Property on Mt. Defiance Range between the middle and south forks of the Snoqualmie River, 6 miles from railroad. Copper, gold, silver.

See also 31, 37, 43, 70, 228, 232, 235.

Gold

232. GOLD IN THE CASCADES. *Blackburn, C. F.*
M. & S. P., vol. 60, no. 25, June 21, 1890, p. 412, $\frac{1}{2}$ column.
Brief discussion of the possibilities of mining in the Cascades, particularly on the Snoqualmie River. Mentions deposits of silver, copper, lead, iron.
233. GOLD IN THE CASCADES. *Blackburn, C. F.*
M. & S. P., vol. 61, no. 6, Aug. 9, 1890, p. 91, $\frac{1}{2}$ column.
Free-milling gold and silver on Mt. Si, North Bend. On property of Cascade Gold Mining & Milling Co. Describes ore body and development.
234. *GOLD DISCOVERED IN SUBURBS OF SEATTLE IN BLACK AND RUBY SAND.
M. & S. P., vol. 88, no. 17, Apr. 23, 1904, p. 291.
235. APEX GOLD MINE. *Adair, J. B., and Giffin, Abner.*
N. W. M. J., vol. 3, no. 5, May 1907, p. 61, 2 pp.
A description of the vein system, equipment, development, and history of the property in the Money Creek district.
See also 37, 43, 231.

Iron

See 31, 97, 98, 232.

Lead

See 37, 43, 228, 232.

Molybdenum

See 99.

Silver

See 37, 43, 228, 230, 231, 232, 233.

Zinc

See 228.

KITSAP COUNTY

Tin

236. *AT PROPERTY OF COOK-KITCHELL MINING CO.
M. & S. P., vol. 71, no. 19, Nov. 9, 1895, p. 306.
See also 20.

KITITAS COUNTY

Articles of a general character

237. *SWAUK MINING DISTRICT.
M. & S. P., vol. 70, no. 11, Mar. 16, 1895, p. 171.
Description of district and some production figures.
238. *SWAUK DISTRICT. NOTES ON DEVELOPMENT.
M. & S. P., vol. 107, no. 8, Aug. 23, 1913, p. 320.
See also 20, 23, 31, 37, 43.

Antimony

239. *DISCOVERED NEAR CLE ELUM.

M. & S. P., vol. 77, no. 25, Dec. 17, 1898, p. 613.
See also 31, 251.

Copper

240. *ON DIVIDE BETWEEN TEANAWAY AND INGALLS CREEK.

M. & S. P., vol. 67, no. 13, Sept. 23, 1893, p. 207.

241. *SKOOKUM COPPER MINING CO. OF ROSLYN. PROPERTY AT CLE ELUM.

M. & S. P., vol. 92, no. 7, Feb. 17, 1906, p. 115.
See also 23, 31, 43, 251.

Gold

242. GOLD MINING IN CENTRAL WASHINGTON. *Smith, Geo. Otis.*

U. S. G. S., Bull. 213, 1903, pp. 76-80.

Describes auriferous gravels and gold quartz veins of the Swauk and Peshastin districts. Details of the vein and development of the Warrior General property in the Peshastin district.

243. GOLD MINING IN CENTRAL WASHINGTON.

N. W. M. N., vol. 2, no. 4, Mar. 1908, p. 73.

A description of the Swuak and Peshastin districts.

244. *GOLD FROM DECOMPOSED QUARTZ VEIN IN THE SWAUK DISTRICT.

M. & S. P., vol. 62, no. 24, June 13, 1891, p. 373.

245. *DISCOVERIES IN KITTITAS COUNTY. GREAT EXCITEMENT IN ELLENSBURG.

M. & S. P., vol. 63, no. 6, Aug. 8, 1891, p. 85.

246. *FREE-MILLING GOLD DISCOVERED ON MENASTASH CREEK, NEAR ELLENSBURG.

M. & S. P., vol. 63, no. 10, Sept. 5, 1891, p. 149.

247. *PLACER GOLD NEAR THORPE ON YAKIMA RIVER.

M. & S. P., vol. 83, no. 12, Sept. 21, 1901, p. 126.

248. *FREE MILLING GOLD, 30 MILES FROM ELLENSBURG, ON WEST SLOPE DIVIDE BETWEEN SWAUK CREEK AND LYONS GULCH.

M. & S. P., vol. 86, no. 22, May 30, 1903, p. 357.

249. SWAUK GOLD PLACER DISTRICT. SHORT DESCRIPTIONS.

M. & S. P., vol. 87, no. 8, Aug. 22, 1903, p. 123, ½ column.

250. *NEW DISCOVERY OF PLACER GOLD NEAR LIBERTY, SWAUK DISTRICT.

M. & S. P., vol. 108, no. 11, Mar. 14, 1914, p. 473.

251. DOVER MINING CO.

M. & S. P., vol. 108, no. 14, Apr. 4, 1914, p. 593.

*Properties in Cle Elum district, gold, silver, copper, lead, antimony; properties in Swauk district, gold, silver.

252. *DISCOVERED IN THE MENASTASH CANYON, 15 MILES FROM ELLENSBURG.
E. & M. J., vol. 52, no. 4, July 25, 1891, p. 108.
Placer gold, silver ledges.
253. THE MINES OF KITTITAS COUNTY.
E. & M. J., vol. 54, no. 26, Dec. 24, 1892, p. 608, 1½ columns. Special correspondence.
Description of development and ore bodies of Peshastin district, and of Swauk placers.
254. *PLACER GOLD DISCOVERED ON YAKIMA RIVER NEAR ELLENSBURG.
E. & M. J., vol. 88, no. 8, Aug. 21, 1909, p. 384.
255. *PLACER GOLD DISCOVERED NEAR THRALL ON YAKIMA RIVER.
E. & M. J., vol. 90, no. 8, Aug. 20, 1910, p. 384.
256. *PLACER GOLD DISCOVERED IN BURBANK CANYON NEAR ELLENSBURG.
E. & M. J., vol. 95, no. 14, Apr. 5, 1913, p. 733.
See also 23, 31, 37, 43.

Iron

257. IRON ORES, RESIDUAL CONCENTRATION BY WEATHERING AS A MODE OF GENESIS OF. *Kimball, James P.*
American Geologist, vol. 21, 1898, pp. 155-163.
Describes geologic occurrences and nature of the iron ores of Clealum River; quality of ores of East Mountain, Duke and Iron Bluffs.
258. IRON ORES, THE CLEALUM, WASHINGTON.
Smith, Geo. Otis, and Willis, Bailey.
T. A. I. M. E., 1900, vol. 30, p. 356.
A description of the location, geology, and genesis.
259. CLEALUM IRON ORES. *Courtis, W. M.*
T. A. I. M. E., vol. 30, 1901, pp. 1116-1117.
Gives analysis of Clealum iron ores.
260. *ON IRON MOUNTAIN.
M. & S. P., vol. 62, no. 9, Feb. 28, 1891, p. 133.
Large deposit. Blast furnace to test ores to be erected.
261. *NEED OF CAPITAL TO DEVELOP ORE BODIES OF KITTITAS COUNTY.
M. & S. P., vol. 62, no. 22, May 30, 1891, p. 339.
262. COMMITTEE OF TACOMA CHAMBER OF COMMERCE TO INVESTIGATE DEPOSITS NEAR CLEALUM AND ELLENSBURG.
M. & S. P., vol. 63, no. 1, July 4, 1891, p. 3.
See also 97, 98.

Lead

See 251.

Nickel

See 23.

Quicksilver

263. *WASHINGTON QUICKSILVER CO., MINE NEAR ROSLYN.
M. & S. P., vol. 90, no. 7, Feb. 18, 1905, p. 111.
See also 23, 31.

Silver

264. *SYLVANITE IN THE HANS WAGNER MINE IN BODY OF GOLD-SILVER ORE, SWAUK DISTRICT.

M. & S. P., vol. 94, no. 11, Mar. 16, 1907, p. 327.

See also 23, 43, 251, 252.

Mineral paint

265. *IN HORSE CANYON, NEAR ELLENSBURG.

M. & S. P., vol. 62, no. 9, Feb. 28, 1891, p. 133.

Silica

266. *DEPOSIT NEAR ELLENSBURG. NO DETAILED LOCATION.

E. & M. J., vol. 91, Mar. 11, 1911, p. 541.

267. *TRIPOLITE DEPOSIT NEAR ROZO, 12 MILES FROM YAKIMA.

M. & S. P., vol. 72, no. 2, Jan. 11, 1896, p. 31.

Klickitat County

Gold

268. *PLACER DEPOSIT DISCOVERED NEAR GOLDENDALE.

E. & M. J., vol. 56, no. 27, Dec. 30, 1893, p. 674.

Lewis County

Articles of a general character

See 20, 37.

Arsenic

269. *ARSENIC IN WASHINGTON.

M. & M., vol. 22, no. 11, June 1902, p. 501, correspondence, $\frac{1}{2}$ column.
Account of deposit of realgar, 50 miles southeast of Tacoma.

270. *NOTE OF PRODUCTION AT MINERAL CREEK.

U. S. G. S., Min. Res. of U. S., 1903, p. 330.

271. *NOTE ON ARSENIC PLANT AT MINERAL. TO PRODUCE WHITE ARSENIC FROM REALGAR.

U. S. G. S., Min. Res. of U. S., 1906, p. 1055.

272. *ARSENIC MINE AT MINERAL CREEK, 50 MILES EAST OF TACOMA.

M. & S. P., vol. 85, no. 2, July 12, 1902, p. 29.

273. *ARSENIC MINE NEAR ELBE, PIERCE COUNTY. PROBABLY AT MINERAL, LEWIS CO.

M. & S. P., vol. 91, no. 8, Aug. 19, 1905, p. 131.

See also 68.

Copper

See 37.

Gold

274. *GOLD-QUARTZ IN GREEN RIVER MINING DISTRICT, SOUTHERN LEWIS COUNTY.
M. & S. P., vol. 67, no. 7, Aug. 12, 1893, p. 110.
275. *LOW-GRADE FREE-MILLING GOLD ORE DEPOSIT NEAR MAYFIELD, LEWIS COUNTY. EXTENDS ACROSS COWLITZ RIVER AND WINSTON AND SALMON CREEKS.
M. & S. P., vol. 98, no. 11, Mar. 13, 1909, p. 371.
276. *FURTHER DESCRIPTION OF MAYFIELD, LEWIS COUNTY, DEPOSIT IN BASALT.
M. & S. P., vol. 98, no. 19, May 8, 1909, p. 647.
See also 37.

Lead

See 37.

Nickel

277. *DEPOSIT DISCOVERED AT HEAD OF COWLITZ RIVER, NEAR MT. RAINIER.
E. & M. J., vol. 62, no. 9, Aug. 29, 1896, p. 207.
Large deposit.

Quicksilver

278. *NOTE ON THE BEGINNING OF RETORTING NEAR MORTON.
U. S. G. S., Min. Res. of U. S., 1915, p. 274 (Part I).

Silver

See 37.

Graphite

279. SHORT DESCRIPTION OF PROPERTY OF OLYMPIC GRAPHITE CO. IN CASCADE MOUNTAINS.
E. & M. J., vol. 56, no. 22, Nov. 25, 1893, p. 554.

Sulphur

280. *IN CASCADE MOUNTAINS, NEAR SULPHUR SPRINGS, LEWIS COUNTY, OR SULPHUR CREEK, SNOHOMISH COUNTY.
U. S. G. S., Min. Res. of U. S., 1916, p. 416 (Part II).

LINCOLN COUNTY

Articles of a general character

See 37.

Copper

See 281.

Lead

281. *RICH DEPOSIT NEAR DAVENPORT, IN EGYPT DISTRICT.
M. & S. P., vol. 66, no. 4, Jan. 28, 1893, p. 62.
Galena with copper and bromides of silver.

282. *GOOD ORE IN GALENA HILL MINE, NEAR REARDAN, WEST OF SPOKANE.

M. & S. P., vol. 108, no. 23, June 6, 1914, p. 947.

See 37.

Silver

See 37, 281.

Opal

283. *REPORTED IN LINCOLN COUNTY. FOUND TO BE NOT GENUINE.

U. S. G. S., Min. Res. of U. S., 1893, p. 698.

Talc

284. *DEPOSIT NEAR REARDAN.

E. & M. J., vol. 103, no. 24, June 16, 1917, p. 1088.

MASON COUNTY

Copper

285. *DISCOVERED IN OLYMPIC RESERVE ON THE NORTH FORK OF THE SKOKOMISH RIVER. ASSOCIATED WITH MANGANESE. LARGE DEPOSIT.

E. & M. J., vol. 96, no. 9, Aug. 30, 1913, p. 426.

286. *PROPERTY ON OLYMPIC PENINSULA. FOUR PER CENT COPPER ASSOCIATED WITH MANGANESE.

M. & S. P., vol. 107, no. 8, Aug. 23, 1913, p. 321.

Iron

See 97, 98.

Manganese

287. *TRIPLE TRIP MINING & MILLING CO., 80 MILES FROM SEATTLE, NEAR HEAD OF HOODS CANAL.

M. & S. P., vol. 101, no. 4, July 23, 1910, p. 124.

See also 285, 286.

OKANOGAN COUNTY

Articles of a general character

288. MINING IN OKANOGAN COUNTY.

M. & S. P., vol. 80, no. 4, Jan. 27, 1900, p. 99, 2 columns.

General article.

289. OKANOGAN MOUNTAINS, RECONNAISSANCE INTO.

Evans, Horace F.

M. W., vol. 28, 1908, Feb. 8, p. 254; Feb. 22, p. 334; Mar. 14, p. 449; Mar. 28, p. 527; Apr. 11, p. 595; Apr. 18, p. 638; Apr. 25, p. 672; May 2, p. 725.

A series of notes on the geology of the Cascade and Okonagon Mountains. Not an account of a reconnaissance in the Okanogan Mountains as suggested.

290. RUBY DISTRICT, WASHINGTON, IN. *Wise, O. B.*

N. W. M. N., vol. 7, no. 6, p. 101, Sept. 1912.

Account of the opening up of this district with output and list of minerals found in the camp.

291. MYERS CREEK MINING DISTRICT, GEOLOGY AND ORE DEPOSITS OF THE. *Umpleby, Jos. B.*

W. G. S., Bull. 5, Part I, 1911.

Gives physiography, general geology, economic geology, and description of the following properties:— Grant property, copper, gold, silver; Monterey property; Nip and Tuck property, gold, silver, copper; Myers Creek Mining Co.'s property, copper; Number Nine property, copper; Neutral property, copper; Rainbow property; Aztec property, copper; Crystal Butte property; Apex Mining Co., gold, silver, lead, zinc, copper; Butcher Boy property, gold, lead, zinc; Molson Gold Mining Co., gold; Mad River Mining Co.; Olentangy group, gold, copper, lead, zinc; Delate claim, lead, copper.

292. OROVILLE-NIGHTHAWK MINING DISTRICT, GEOLOGY AND ORE DEPOSITS OF. *Umpleby, Jos. B.*

Includes physiography, general and economic geology of the district and detailed description of the following mines and principal properties:— Kelsey group, gold, silver, copper; Okanogan Free Gold mine, gold; Golden Chariot, gold, copper; Ohio, copper; Forty-ninth Parallel Mining Co., gold, copper; Nighthawk group, lead, silver; Favorite Mining Co.; Little Chopaka group, gold, silver, lead; Summit claim, lead, copper, zinc; Number One group, silver, lead, gold, copper; California claim, lead, zinc, copper; Peerless group, copper; Caaba Lead, lead, gold, silver; Prize group, silver, lead, gold; Ruby mine, copper, lead, zinc, gold, silver; Mountain Sheep, copper, lead, zinc, gold, silver; Gold Zone, gold, copper, lead, zinc; Rich Bar, gold, copper, lead, zinc, silver; Similkameen placers, gold; Kimberly, lead, gold, silver; Triune mine, gold, lead; Hiawatha, gold, lead, copper; Trinity group; Hornsilver group, silver, gold, lead, zinc, copper; Maqua group, gold, silver, lead, zinc, copper; Bellevue group, gold, silver, copper; Bull Frog group; Palmer Lake group, gold; Ivanhoe mine, silver, gold; Rainbow mine, gold, silver, copper, lead; Copper World Extension, copper, gold, silver; Second Prize group, gold; Leadville group, gold, lead, copper; Pinnacle mine, gold; Palmer Mountain, Tunnel & Power Co.'s properties, gold; Antimony property, antimony; Copper World, copper.

293. RECONNAISSANCE OF THE CONCONULLY AND RUBY MINING DISTRICTS. *Jones, Edward L., Jr.*

U. S. G. S., Bull. 640 B, 1916, pp. 10-36, inc.

Gives history, geography, topography, geology, ore deposits, and results of metallurgical investigations. Map of region. Describes in detail the following properties:—

Conconully district: Key mine, lead, copper, zinc; Tough Nut, lead, copper, zinc; Salmon River Chief, lead, copper, zinc; Copper King, lead, copper, zinc, silver; Esther, lead, copper, zinc; Homestake, Monitor, copper, zinc; Star, copper; Washington Consolidated Mines and Reduction Co., lead, copper, zinc, molybdenum; Leuena, copper, silver; Lady of the Lake, lead, copper, zinc.

Ruby district: Peacock Mining & Milling Co., lead, copper, zinc, silver; Buckhorn group; Plant-Callahan group, copper, silver; First Thought; Last Chance, lead, copper, zinc; Fourth of July, silver; Arlington mine, lead, copper, zinc, gold, silver.

Other properties in the county: Q. S. Copper Co., Sec. 27, T 37 N, R 25 E, gold, silver, copper; Blue Lake, Sec. 28, T 37 N, R 25 E, copper; Okanogan Copper Co., Sec. 29, T 37 N, R 25 E, gold, copper; The Gold Quarry group, Sec. 29, T 37 N, R 25 E, gold; Dorian claim, Sec. 34, T. 35 N. R 25E, mariposite (chromium mica).

See also 20, 24, 29, 37, 38, 43, 161.

Antimony

294. *ANTIMONY SULPHIDE AT RUBY MINING CO., MT. CHOPACA.

M. & S. P., vol. 92, no. 3, January 20, 1906, p. 46.

Values in silver and copper.

295. *STIBNITE IN ANTIMONY QUEEN, METHOW.

M. & S. P., vol. 94, no. 2, Jan. 12, 1907, p. 41.

296.*IN DIXIE QUEEN MINE NEAR METHOW.

M. & S. P., vol. 94, no. 9, Mar. 2, 1907, p. 264.

See also 292, 306.

Arsenic

See 37.

Copper

297. COPPER DEPOSITS OF LAKE OSOYOOS, WASHINGTON.

Evans, Horace F.

M. W., vol. 29, Sept. 5, 1908, pp. 361-362.

Description of the copper prospects of the region and an estimate of their geologic age.

298. *COPPER AND GOLD ON BUCK HORN MOUNTAIN, GRANT MINE.

M. & S. P., vol. 85, no. 24, Dec. 13, 1902, p. 347.

299. *SHEET OF NATIVE COPPER ON FOOT WALL OF COPPER WORLD PROPERTY.

M. & S. P., vol. 92, no. 25, June 23, 1906, p. 427.

300. *A NEW OLD CAMP. *Esch, Peter.*

A. & N. W. M. J., vol. 10, no. 2, Feb. 1917, p. 29, 1½ pp.

Copper, gold, silver, zinc. A description of the revival of mining in the Methow district, Okanogan County, and Slate Creek district, Whatcom County. Mentions following properties:— Bonita on Slate Creek; Crescent on Twisp River; Spokane group near Twisp. Illustrated.

See also 24, 29, 37, 38, 43, 70, 99, 291, 292, 293, 294, 305, 306, 308, 314, 320.

Gold

301. *RICH PLACER DEPOSITS ON SIMILKAMEEN RIVER.

M. & S. P., vol. 62, no. 6, Feb. 7 1891, p. 85.

302. *PLACER GOLD ON PALMER MOUNTAIN.

M. & S. P., vol. 63, no. 7, Aug. 15, 1891, p. 101.

303. AN ACCOUNT OF THE DISCOVERY IN THE SHAKER BEND OF THE SIMILKAMEEN RIVER, JUST BELOW SIMILKAMEEN FALLS. IN QUARTZ DIKE.

M. & S. P., vol. 64, no. 25, June 18, 1892, p. 443.

304. *PLACER GOLD, 6 MILES SOUTH OF CHESAW.

M. & S. P., vol. 85, no. 14, Oct. 4, 1902, p. 198.

305. RUBY MINE. ON CHOPACA MOUNTAIN, NEAR NIGHTHAWK.

M. & S. P., vol. 90, no. 6, Feb. 4, 1905, p. 78.

*Gold, silver, copper, traces of zinc and lead.

M. & S. P., vol. 90, no. 7, Feb. 18, 1905, p. 111.

*Brief description of ore body.

306. MOSES DISTRICT.

M. & S. P., vol. 97, no. 23, Dec. 5, 1908, p. 761.

*Apache Mining Co., gold, silver, lead, copper, antimony, zinc.

307. *PLACERS ON SIMILKAMEEN RIVER.

M. & S. P., vol. 100, no. 17, Apr. 23, 1910, p. 600.

308. SHERIDAN CAMP, OKANOGAN AND FERRY COUNTIES.

M. & S. P., vol. 107, no. 22, Nov. 29, 1913, p. 867.

*Ore running \$182 per ton in gold, silver and copper, discovered 10 miles west of Republic.

See also 37, 38, 43, 291, 292, 293, 298, 300, 320.

Iridium

309. *IRIDIUM PLACER DEPOSIT NEAR WANNACUT LAKE.

A. & N. W. M. J., vol. 4, no. 4, Apr. 1914, p. 92.

Iron

310. *MAGNETITE IN PYRRHOTITE ON EAST SIDE OF COPPER MOUNTAIN.

M. & S. P., vol. 97, no. 14, Oct. 3, 1908, p. 149.

Aztec (Aztec?) and other claims.

Lead

311. *DELA TE MINE AT CHESAW.

M. & S. P., vol. 87, no. 18, Oct. 31, 1903, p. 295.

312. *GALENA AT SPOKANE MINE, 2 MILES EAST OF TWISP.

M. & S. P., vol. 92, no. 3, Jan. 20, 1906, p. 46.

313. *GALENA AND CARBONATE ORE AT VIOLA COPPER-GOLD MINING Co.

M. & S. P., vol. 93, no. 16, Oct. 20, 1906, p. 469.

314. *GALENA ON DEWEY MOUNTAIN.

M. & S. P., vol. 97, no. 23, Dec. 5, 1908, p. 761.

Multnomah Mining Co., on Nespelem Creek. Also copper.

See also 29, 37, 38, 43, 291, 292, 293, 305, 306, 325.

Molybdenum

315. *IN THE MINERAL HILL MINING CO. PROPERTY AT CONCONULLY.

M. & S. P., vol. 92, no. 13, March 31, 1906, p. 229.

316. *AT OROVILLE. VEIN 10 INCHES TO 4 FEET WIDE.

M. & S. P., vol. 92, no. 25, June 23, 1906, p. 427.

317. *IN VEIN ON THE PIONEER GROUP, 25 MILES NORTH OF CONCONULLY.

M. & S. P., vol. 94, no. 7, Feb. 16, 1907, p. 201.

See also 37, 38, 43, 99, 293.

Nickel

318. *NICKEL ORE REPORTED. LOCATION NOT STATED.

M. & S. P., vol. 72, no. 7, Feb. 15, 1896, p. 131.

Platinum

319. *PLATINUM CLAIM ON SLATE CREEK, SIMILKAMEEN DISTRICT, NEAR LOOMIS.

M. & S. P., vol. 86, no. 10, Mar. 7, 1903, p. 159.

320. *TRACES OF PLATINUM IN THE GOLD-SILVER-COPPER ORE OF PEERLESS MINING CO. ON LITTLE MT. CHOPACA.

M. & S. P., vol. 98, no. 16, Apr. 17, 1909, p. 541.

321. *PLACER DEPOSITS NEAR RIVERSIDE.

U. S. G. S., Min. Res. of U. S., 1916, p. 11 (Part I).

*On south fork, Lewis River in Clarke County.

Silver

322. *RUBY SILVER. MINERAL HILL MINE, 2 MILES WEST OF CON-
CONULLY.

M. & S. P., vol. 88, no. 4, Jan. 23, 1904, p. 70.

323. *RUBY MINE, CHOPACA MOUNTAIN.

*Ruby silver and silver glance.

M. & S. P., vol. 92, no. 5, Feb. 3, 1906, p. 78.

324. *DOUBLE HEADER MINING CO., NESPELEM.

M. & S. P., vol. 102, no. 22, June 3, 1911, p. 773.

325. LONE STAR MINE, NEAR CONCONULLY.

M. & S. P., vol. 106, no. 26, June 28, 1913, p. 1007.

*Silver-lead.

See also 29, 37, 38, 43, 291, 292, 293, 294, 300, 305, 306, 308, 320.

Tungsten

326. TUNGSTEN ORE IN WASHINGTON.

E. & M. J., vol. 80, Nov. 11, 1905, p. 877.

Brief account of discovery of a deposit in T. 40 N. R. 22 E, near Loomis.

327. TUNGSTEN ORE IN WASHINGTON. *Joseph, M. H.*

E. & M. J., vol. 81, Mar. 3, 1906, p. 409.

Brief account of discovery of a deposit in T. 40 N. R. 22 E, near Loomis.

328. *THREE-FOOT VEIN REPORTED AT COPPER WORLD EXTENSION.

M. & S. P., vol. 91, no. 18, Oct. 28, 1905, p. 300.

329. *WOLFRAMITE IN CASCADE MOUNTAINS, NEAR LOOMIS.

M. & S. P., vol. 94, no. 1, Jan. 5, 1907, p. 11.

Veins from 4 to 7 feet, and from 10 to 24 inches wide. Ten per cent wolframite.

330. *WOLFRAMITE DISCOVERED NEAR CATHEDRAL PEAK NEAR INTER-
NATIONAL BOUNDARY.

M. & S. P., vol. 111, no. 23, Dec. 4, 1915, p. 870.

Zinc

331. *ZINC BLENDE IN MYER'S CREEK DISTRICT. MAD RIVER MINING
Co.

M. & S. P., vol. 92, no. 23, June 9, 1906, p. 391.

See also 29, 37, 291, 292, 293, 300, 305, 306.

Asbestos

332. *LARGE DEPOSIT 14 MILES SOUTHWEST OF TWISP.

M. & S. P., vol. 97, no. 14, Oct. 3, 1908, p. 449.

Magnesium sulphate

333. *EPSOM SALT LAKE, NEAR OROVILLE. LARGE DEPOSIT.

M. & S. P., vol. 111, no. 23, Dec. 4, 1915, p. 870.

Mariposite (chromium mica)

See 293.

Potash

334. *POTASH LAKE DEPOSIT, NORTHWEST OF RIVERSIDE.

A. & N. W. M. J., vol. 8, no. 2, Feb. 1916, p. 45.

Sodium sulphate

335. *SODIUM SULPHATE DEPOSIT OF 40 ACRES, 2 FEET THICK.

E. & M. J., vol. 66, no. 21, Nov. 19, 1898, p. 619.

Good quality; locality indefinite.

336. *DEPOSIT 40 ACRES, 2 FEET THICK, 95 PER CENT PURE, 14 MILES FROM OKANOGAN RIVER, AND 60 MILES FROM REPUBLIC.

E. & M. J., vol. 66, no. 27, Dec. 31, 1898, p. 799.

337. AN ACCOUNT OF THE SODIUM SULPHATE DEPOSIT NEAR OPHIR.

Min. Ind., vol. 7, 1898, p. 621.

Description of the deposit, extent, etc., 95 per cent pure.

PACIFIC COUNTY

Gold

338. *AT SOUTH BEND.

M. & S. P., vol. 104, no. 6, Feb. 10, 1912, p. 258.

PEND OREILLE COUNTY

Articles of a general character

339. THE MINES OF METALINE.

N. W. M. N., vol. 1, no. 9, Aug. 1907, p. 9.

Historical and other facts connected with an important mining district tributary to Spokane.

See also 19, 29, 38, 43.

Copper

See 43, 342.

Gold

340. *PLACERS AT METALINE.

M. & S. P., vol. 68, no. 11, Mar. 17, 1894, p. 175.

See also 29, 43.

Lead

341. LEAD IN 1906. OPERATIONS IN THE METALINE DISTRICT.

U. S. G. S., Min. Res. of U. S., 1906, p. 451.

342. LEAD AND ZINC DEPOSITS IN THE METALINE MINING DISTRICT, NORTHEASTERN WASHINGTON. *Bancroft, Howland C.*

U. S. G. S., Bull. 470, 1911, pp. 188-200.

Includes location and extent, means of access, condition of mining industry, topography, geology, ore deposits, their origin and character, future of the district and detailed description of the following prospects:— Oriole, lead, zinc; Clark property, lead, zinc; Lead King property, lead, zinc; Cliff property, lead; Schellenburg prospects; Riverside property, lead, copper; Meade property, lead, copper.

343. LEAD AND ZINC DEPOSITS IN THE METALINE DISTRICT.

Bancroft, Howland C.

Abstract from Bull. 470 D, U. S. G. S., 1911.

M. & E. W., vol. 35, July 15, 1911, p. 113.

See also 29, 38, 43.

Molybdenum

See 99.

Silver

See 29, 38, 43.

Zinc

344. DEVELOPMENT IN WASHINGTON.

U. S. G. S., Min. Res. of U. S., 1915, p. 923 (Part I), ½ p.

Notes on the Metaline and Northport districts.

See also 29, 342.

PIERCE COUNTY

Articles of a general character

See 20, 31, 37.

Copper

345. *DEPOSIT OF CHALCOPYRITE, DISCOVERED ON CARBON RIVER,
NEAR FAIRFAX.

M. & S. P., vol. 80, no. 6, Feb. 10, 1900, p. 155.

See also 37.

Gold

346. EDITORIAL ON THE GOLD-BEARING CLAIMS IN THE CITY OF TACOMA,
WASH.

E. & M. J., vol. 59, no. 9, Mar. 2, 1895, p. 194.

Describes attempt to show that School Section 16 in the city was a valuable gold property.

347. *PLACER GOLD DISCOVERED BETWEEN GIG HARBOR AND PURDY.

E. & M. J., vol. 64, no. 5, July 31, 1897, p. 139.

348. *FREE-MILLING DEPOSIT ON MARSHALL CREEK, 30 MILES SOUTH-
EAST OF TACOMA.

M. & S. P., vol. 64, no. 19, May 7, 1892, p. 325.

349. *ORE FROM BEAR GAP IN THE CASCADES.

M. & S. P., vol. 95, no. 26, Dec. 28, 1907, p. 801.

"May contain \$8.00 per lb. in gold."

See also 37.

Molybdenum

See 99.

Silver

See 37.

Graphite

350. *DISCOVERED ON SOUTH PRAIRIE CREEK, NEAR WILKESON.

E. & M. J., vol. 64, no. 22, Nov. 27, 1897, p. 649.

SAN JUAN COUNTY

Gold

351. *FREE-MILLING GOLD DISCOVERED ON ORCAS ISLAND.
E. & M. J., vol. 54, no. 10, Sept. 3, 1892, p. 232.
352. *VAST DIKE OF GOLD ORE DISCOVERED ON THE NORTH SIDE OF ORCAS ISLAND.
M. W., vol. 24, no. 16, Apr. 21, 1906, p. 509.

Iron

353. *BROWN HEMATITE ON LOPEZ ISLAND.
N. W. M. J., vol. 4, no. 4, Oct. 1907, p. 67.

SNOHOMISH COUNTY

Articles of a general character

354. INDEX MINING DISTRICT, GEOLOGY AND ORE DEPOSITS OF.
Weaver, Charles E.
W. G. S., Bull. 7, 1912.
Includes physiography, general geology, economic geology and detailed description of the following mines:— Sunset; Nonpareil; Ethel; Kittaning; Merchant; Homestead; Cooperative; Lost Creek; Uncle Sam; Calumet; Florence-Rae; Bitter Creek; Index Bornite; Index Peacock; Gunn Peak; Helena; North Star; Index Independent; Buckeye; Copper Bell; Red Cross; Index granite quarry; Halford granite quarry. History of mining; ore treatment; Copper Bell concentrator (Bunker Hill Mining & Smelting Co.); character and distribution of ore bodies and genesis of ores.
355. INDEX MINING DISTRICT. *Adair, J. B.*
N. W. M. J., vol. 4, no. 4, Oct. 1907, p. 55, 5 pp., illustrated.
Gives a map of the district and section of the workings of the Bunker Hill Mining & Smelting Co. Describes topography, history, production, and geology of the district. Gives a list of properties on Silver Creek, Snohomish County, and describes the following properties:— Index Bornite; Sunset Copper; Nonpareil Consolidated; Kittaning; Galena Copper, New York-Seattle; Ethel Consolidated; Red Cross; Bunker Hill Mining & Smelting Co.
356. MINES IN WASHINGTON.
M. & S. P., vol. 62, no. 9, Feb. 28, 1891, p. 130, 1½ columns.
Describes Silver Creek, Monte Cristo, Sultan, Cascade and Snoqualmie districts.
357. MINING IN THE CASCADES.
A. & N. W. M. J., vol. 9, no. 5, Nov. 1916, p. 115, ¼ column.
An account of the renewal of operations at Monte Cristo, by the Boston-American Mining Co.
358. ORE DEPOSITS OF MONTE CRISTO, WASHINGTON.
Spurr, Josiah Edward.
U. S. G. S., Twenty-second Annual Report, part 3, pp. 785-865, plates 79-82, figures 89-130, 1901.
Gives rock divisions, granite, arkose, andesite, tuffs, slates, tonalite, dacite, rhyolite, basalt and enstatite-peridotite; study of the ores, deposition, when, where and how, mineralization, relative age and position of minerals, characteristics of ore zones and their relation to water zones.

359. MR. SPURR'S CHANGE OF HEART.

N. W. M. J., vol. 5, no. 5, May 1908, p. 82, 1 p.

A letter from Mr. J. E. Spurr to the editor explaining his views on ore deposits, especially in their application to the Monte Cristo district.

360. ORE DEPOSITS OF MONTE CRISTO, WASHINGTON.

Spurr, Josiah Edward.

E. & M. J., vol. 74, pp. 240-241, 4 figures, 1902.

Accessibility, rock formations, ores and their deposition in this district.

361. MONTE CRISTO, WASH., ORE DEPOSITS OF. *Winchell, Horace V.*

American Geologist, vol. 30, pp. 113-118, 1902.

Location and geologic description of the district. Listing the chief ores and describing the occurrence of the joint systems and veins.

362. A HISTORY OF THE MONTE CRISTO DISTRICT.

A. & N. W. M. J., vol. 11, no. 5, Nov. 1917, p. 113, 3 pp.

A description of the topography, transportation, geology, vein system, and ore treatment of the district. Describes operations of the Boston-American and '76 Consolidated Mining Co.

363. THE MONTE CRISTO MINING DISTRICT, WASHINGTON.

Stretch, R. H.

A sketch of the geology and topography of the district.

364. MONTE CRISTO DISTRICT. *Snyder, Carl.*

M. & S. P., vol. 65, no. 25, Dec. 17, 1892, p. 397, 2¼ columns.

Account of discovery of the district and construction of railroads; character of ore bodies, etc.

365. THE ORE DEPOSITS OF MONTE CRISTO. *Lakes, Arthur.*

M. & M., vol. 23, no. 5, Dec. 1902, p. 204, 2½ pp.

An illustrated abstract of Spurr's monograph.

366. DEU PREE LODE, WASHINGTON. *Landes, Henry.*

E. & M. J., vol. 65, no. 2, Jan. 8, 1898, pp. 39-40.

Description of the lodes, country rock, character of the ore, accessibility, of the mine of the Forty-five Consolidated Mining Co., Silverton. Development and aerial tramway.

367. SILVERTON MINING DISTRICT, SNOHOMISH COUNTY, WASH., THE

Stretch, R. H.

E. & M. J., vol. 72, July 27, 1901, p. 105.

368. SILVERTON, THE INDEPENDENT MINE AT. *Stretch, R. H.*

E. & M. J., vol. 73, June 14, 1902, p. 832.

Brief description of workings and ore bodies.

369. SILVERTON DISTRICT.

M. & S. P., vol. 91, no. 2, July 8, 1905, p. 35.

*Resumption of operations at Forty-five mine.

370. WHITE HORSE DISTRICT.

M. & S. P., vol. 78, no. 14, Apr. 8, 1899, p. 380.

E. & M. J., vol. 55, no. 15, Apr. 15, 1893, p. 343, 1 column.

Description of district near Darrington. Silver, copper, and mercury on Gold Mountain.

See also 12, 20, 37, 38, 43, 52.

Antimony

371. *DEPOSIT IN SILVER CREEK DISTRICT.

M. & S. P., vol. 61, no. 11, Sept. 13, 1890, p. 171.

See also 43.

Arsenic

372. *SNOHOMISH COUNTY, SILVER CREEK, ABOVE MINERAL CITY, VICTORY GROUP.

M. & S. P., vol. 85, no. 9, Aug. 30, 1902, p. 122.

Chalcopyrite, arsenical iron, and galena carrying gold, silver, and copper as values.

373. *NEAR INDEX.

M. & S. P., vol. 85, no. 10, Sept. 6, 1902, p. 138.

Yellow sulphide of arsenic with copper, on the claims of Butte & Boston Co. (sold to Cascade Arsenic Mining Co.).

374. *NOTED IN IMPERIAL MINE, SILVERTON. RUNS AS HIGH AS 15 PER CENT.

M. & S. P., vol. 91, no. 11, Sept. 9, 1905, p. 183.

See also 37, 43, 68, 379.

Chromium

375. *CHROME IRON DISCOVERED IN THE SULTAN BASIN.

A. & N. W. M. J., vol. 9, no. 5, Nov. 1916, p. 139.

Copper

376. COPPER ORES IN THE CASCADE MOUNTAINS. *Stretch, R. H.*

E. & M. J., vol. 78, no. 20, Nov. 17, 1904, pp 789-790, 3 figures.

Extent of the copper belt, its physical features, the rock series accompanying it, occurrence of the ore, and description of the Clear Creek Basin, near Darrington.

377. *CHALCOPYRITE IN TROUT CREEK MINES, INDEX DISTRICT.

M. & S. P., vol. 67, no. 21, Oct. 18, 1893, p. 334.

378. *ON JUMBO MOUNTAIN, NEAR DARRINGTON.

M. & S. P., vol. 92, no. 8, Feb. 24, 1906, p. 133.

379. DEL-CAMPO METALS CO.

M. & S. P., vol. 99, no. 26, Dec. 25, 1909, p. 871.

*Copper sulphide associated with some arsenic in claims near Monte Cristo.

380. *WASHINGTON-IOWA PROPERTY, ON SILVER CREEK, ABOVE MINERAL CITY.

M. & S. P., vol. 101, no. 2, July 9, 1910, p. 63.

Copper, iron, lead, zinc.

381. *AT GLACIER PEAK MINING CO., NEAR SUIATTLE PASS, 27 MILES FROM LUCERNE ON LAKE CHELAN.

M. & S. P., vol. 105, no. 22, Nov. 30, 1912, p. 711.

See also 37, 43, 70, 71, 354, 355, 370, 372, 343, 385.

Gold

382. *HYDRAULIC MINING ON THE STILLAGUAMISH RIVER. LOCATION INDEFINITE.

M. & S. P., vol. 64, no. 19, May 7, 1892, p. 335.

383. *PLACER GOLD DISCOVERED NEAR OSO.

M. & S. P., vol. 84, no. 1, Jan. 4, 1902, p. 13.

384. SULTAN PLACER MINING CO.

M. & S. P., vol. 90, no. 19, May 13, 1905, p. 309.

*Note on construction of plant.

385. *LARGE QUANTITY OF FLOAT PEACOCK ORE AND GOLD DISCOVERED
IN PILCHUCK VALLEY.

E. & M. J., vol. 92, no. 13, Sept. 23, 1911, p. 614.

See also 37, 38, 43, 72, 372, 390.

Iron

386. *BOG IRON ORE, NEAR ARLINGTON.

M. & S. P., vol. 93, no. 8, Aug. 25, 1906, p. 223.

See also 380.

Lead

387. *GALENA AND CARBONATES NEAR VANDALIA, SILVER CREEK DISTRICT.

M. & S. P., vol. 62, no. 25, June 20, 1891, p. 389.

388. *CASCADE MINING CO., 4 MILES FROM RAILROAD, NEAR BERLIN.

M. & S. P., vol. 98, no. 20, May 15, 1909, p. 680.

Carries silver.

See also 37, 38, 43, 372, 380, 391.

Molybdenum

See 99.

Quicksilver

389. *DISCOVERED IN THE ECLIPSE LODGE IN THE STILLAGUAMISH DISTRICT.

U. S. G. S., Min. Res. of U. S., 1913, p. 210 (Part I).

390. *QUICKSILVER MINE IN SNOHOMISH COUNTY.

M. & S. P., vol. 110, no. 19, May 8, 1915, p. 742.

Eclipse Consolidated Mining & Investment Company of Seattle; also gold and silver. Furnace operating.

See also 370.

Silver

391. *SILVER-LEAD DISCOVERED AT THE HEAD OF THE SAUK RIVER.

M. & S. P., vol. 61, no. 21, Nov. 22, 1890, p. 333.

See also 37, 38, 43, 370, 388, 390.

Tin

392. *PLACER TIN IN CASCADES NEAR SNOHOMISH, LOCATION NOT SPECIFIED.

M. & S. P., vol. 87, no. 18, Oct. 31, 1903, p. 295.

Uranium

393. *URANIUM ORE DISCOVERED FIVE MILES WEST OF SULTAN.

A. & N. W. M. J., vol. 9, no. 4, Oct. 1916, p. 110.

Zinc

394. *NEAR ARLINGTON.

M. W., vol. 23, no. 26, Dec. 30, 1905, p. 735

See also 37, 43, 380.

SKAGIT COUNTY

Articles of a general character

395. SKAGIT'S MINERAL WEALTH.

M. & S. P., vol. 62, no. 21, May 23, 1891, p. 325, $\frac{1}{2}$ column.

Resume of development in the Cascade district. Describes need of roads.

396. THUNDER CREEK MINING DISTRICT. Grove, C. E.

P. M. J., vol. 1, no. 2, Aug. 1912, p. 1, $2\frac{1}{2}$ pp. illustrated.

Lead, copper, silver. Describes development in this district in the southeast corner of Skagit County. Describes development of the following:—Skagit Queen group; Silver Tip group; Thunder Creek group, lead, silver; Logan's group; Red Mountain group, copper, lead. Describes also geology and topography of district.

See also 20, 43, 52.

Arsenic

397. *NOTE ON DEPOSIT OF REALGAR NEAR CLARK LAKE (CLEAR LAKE?).

U. S. G. S., Min. Res. of U. S., 1914, p. 959, (Part I).

See also 68.

Chromium

398. *CHROME IRON ON AN ISLAND OF SKAGIT COUNTY.

E. & M. J., vol. 63, no. 21, May 22, 1897, p. 523.

399. *CHROME IRON ON CYPRESS ISLAND.

N. W. M. J., vol. 4, no. 4, Oct. 1907, p. 67.

See also 405.

Copper

See 43, 396, 407.

Gold

400. *RICH PLACER FIELDS, DISCOVERED ON BAKER RIVER, ABOVE CONFLUENCE OF SKAGIT. MAY BE IN WHATCOM COUNTY.

M. & S. P., vol. 76, no. 6, Feb. 5, 1898, p. 162.

See also 43, 407.

Iridium

See 43.

Iron

401. *MAGNETITE ON SAMISH BAY.

N. W. M. J., vol. 4, no. 4, Oct. 1907, p. 67.

See also 97, 98, 399, 400.

Lead

See 43, 396, 406, 408.

Molybdenum

402. *MOLYBDENUM REPORTED "IN WASHINGTON, NEAR SKAGIT, AND ABOUT 1000 FEET BELOW THE WHITE PASS RAILROAD TUNNEL." (?)

Considerable deposit 5 to 8 feet thick, uncovered for 800 ft.

U. S. G. S., Min. Res. of U. S., 1899, p. 307.

403. *DISCOVERED IN SKAGIT COUNTY. LOCATION NOT STATED.
M. & S. P., vol. 79, no. 19, Nov. 4, 1899, p. 523.
See also 99.

Nickel

404. *NEAR SEDRO WOOLLEY.
U. S. G. S., Min. Res. of U. S., 1900, p. 245.

Osmium

See 43.

Platinum

405. *DISCOVERED IN MASSIVE CHROMITE AT ANACORTES.
U. S. G. S., Min. Res. of U. S., 1905, pp. 424 and 1175.
See also 43.

Silver

406. *RICH SILVER ORE DISCOVERED ON CASCADE RIVER.
M. & S. P., vol. 61, no. 6, Aug. 9, 1890, p. 87.
Runs 60 ounces to a ton, and 60 to 65 per cent lead.
407. *CHLORIDE AND BROMIDE OF SILVER AT SKAGIT QUEEN NEAR MARBLEMOUNT.
M. & S. P., vol. 97, no. 21, 1908, p. 686.
With gold and copper.
408. THE GREAT SILVER-LEAD DISTRICT OF THE CASCADE RANGE IN WASHINGTON. *Adair, J. B.*
N. W. M. J., vol. 3, no. 6, June 1907, p. 75, 3 pp., map.
(Skagit and Chelan counties.)
A description of the geology and ore bodies of the districts around Thunder and Bridge Creeks, Skagit and Chelan counties. Describes vein system of the property of the Standard Reduction & Development Co., etc.
See also 43, 396.

Zinc

See 43.

Asbestos

409. *AT LYMAN.
E. & M. J., vol. 62, no. 6, Aug. 8, 1896, p. 135.
410. *FINE QUALITY, DISCOVERED NEAR HAMILTON.
E. & M. J., vol. 51, no. 12, Mar. 21, 1891, p. 362.
411. *NEAR SKAGIT RIVER IN FOOTHILLS OF CASCADES.
E. & M. J., vol. 65, no. 13, Mar. 26, 1898, p. 383.
Good quality. Associated with magnesite, limestone and eruptive rocks.
See also 38.

Graphite

412. *NEAR SAMISH LAKE. PROPERTY HAS SHIPPED ORE.
E. & M. J., vol. 50, no. 18, Nov. 1, 1890, p. 515.
See also 38.

Mica

See 38.

Strontium

413. *NOTE OF A DEPOSIT OF STRONTIANITE AND CELESTITE NEAR LA CONNER.

U. S. G. S., Min. Res. of U. S., 1915, p. 186 (Part II); 1916, p. 194 (Part II).

Talc

414. *TALC MINE 7 MILES WEST OF ANACORTES.

E. & M. J., vol. 87, no. 26, June 26, 1909, p. 1308.

SKAMANIA COUNTY

Articles of a general character

See 19, 20, 37.

Copper

415. *NEAR STEVENSON. MOUNTAIN KING GROUP AND OTHERS.

M. & S. P., vol. 86, no. 7, Feb. 14, 1903, p. 111.

Copper sulphides carrying gold and silver.

See also 37, 70.

Gold

See 37, 415.

Lead

See 37.

Silver

See 37, 415.

SPOKANE COUNTY

Gold

See 429.

Lead

See 421, 430.

Silver

416. *SILVER ORE DISCOVERED $4\frac{1}{2}$ MILES NORTHWEST OF SPOKANE.

M. & S. P., vol. 108, no. 6, Feb. 7, 1914, p. 272.

Runs from 10 ounces per ton up.

See also 421.

Tin

417. TIN ORE AT SPOKANE, WASHINGTON. *Collier, Arthur J.*

U. S. G. S., Bull. 340, 1908, pp. 295-305.

A compact description of geography, topography, and geology of Spokane and surrounding country; gives analysis and occurrence of the tin-bearing ore.

418. TIN ORE AT SPOKANE, WASHINGTON. *Collier, Arthur J.*

M. W., vol. 29, Dec. 5, 1908, p. 852.

Extract from Economic Bulletin 340, (1907), U. S. G. S. An account of the occurrence of a deposit of cassiterite at Silver Hill, southeast of Spokane.

419. *ACCOUNT OF DEPOSIT AND OCCURRENCE OF ORE AT SILVER HILL, SOUTHEAST OF SPOKANE.
Min. Ind., vol. 16, 1907, p. 862.
420. DESCRIPTION OF TIN ON MORAN PRAIRIE, 6 MILES EAST OF SPOKANE.
M. & S. P., vol. 94, no. 19, May 11, 1907, p. 584, $\frac{1}{2}$ column.
421. A TIN DEPOSIT NEAR SPOKANE. *Whitman, A. R.*
M. & S. P., vol. 94, no. 22, June 1, 1907, p. 697, $1\frac{1}{2}$ pp.
Describes deposit on south slope Silver Hill, 12 miles south of Spokane. Geology and ore bodies. Mentions argentiferous galena, wolframite, and scheelite as associated minerals.
422. TIN DEPOSIT NEAR SPOKANE. *Whitman, A. R.*
M. & S. P., vol. 4, June 13, 1907, p. 49, 1 figure.
Gives location of mine, economic importance, including tests of the ore.
423. A TIN DEPOSIT NEAR SPOKANE. *Whitman, A. R.*
M. & S. P., vol. 95, no. 2, Aug. 13, 1907, p. 49, $1\frac{1}{2}$ columns, illustrated.
Economic importance of deposit.
424. TIN ORE AT SPOKANE.
M. & S. P., vol. 96, no. 16, Apr. 18, 1908, p. 536, 1 column.
Brief resume of Whitman's articles.
425. TIN ON MORAN PRAIRIE.
N. W. M. N., vol. 1, no. 6, May 1907, p. 20.
An account of the discovery of tin near Spokane.
426. TIN ORE AT SPOKANE, WASHINGTON.
N. W. M. N., vol. 2, no. 6, May 1908, p. 126.
See Contributions to Economic Geology, 1907, U. S. G. S. An account of a discovery at Silver Hill, southeast of Spokane.
427. TIN DEPOSITS OF THE WORLD, TABLE OF.
Economic Geology, vol. 7, p. 212.
Notes mode of occurrence of the deposit near Spokane.

Tungsten

428. *IN MINES SPOKANE TIN CO., 6 MILES EAST OF SPOKANE.
M. & S. P., vol. 94, no. 24, June 15, 1907, p. 743.
See also 421.

Zinc

429. *IN GOLD-BEARING ORE AT W. & K. MINE, 33 MILES SOUTH OF SPOKANE.
M. & S. P., vol. 93, no. 26, Dec. 29, 1906, p. 773.

Graphite

430. *PURE DEPOSIT ON SHEEP MOUNTAIN, EAST OF SPOKANE.
M. & S. P., vol. 93, no. 20, Nov. 17, 1906, p. 591.
Forty feet wide, parallel to vein of galena.

Mica

See 38.

Silica

431. *DEPOSIT 5,000,000 TONS, 15 MILES NORTH OF SPOKANE.
M. & S. P., vol. 106, no. 11, Mar. 13, 1913, p. 430.
432. *VALUABLE SILICA PROPERTY IN WASHINGTON.
M. & E. W., vol. 45, no. 23, Dec. 2, 1916, p. 955, $\frac{1}{2}$ column, illustrated.
Description of property near Spokane. Spokane Silica Co.

STEVENS COUNTY

Articles of a general character

433. CEDAR CANYON MINING DISTRICT. *Burdsal, C. W.*
Mining, vol. 1, pp. 191-192, 1896.
Brief description of the geology of the region and the occurrence of the silver ore.
434. COLVILLE DISTRICT.
M. & S. P., vol. 61, no. 24, Dec. 13, 1890, p. 381.
Resume of mining operations.
435. CHEWELAH, WORK AT.
M. & S. P., vol. 106, no. 7, Feb. 15, 1913, p. 289, 1 column.
*Production figures of the camp.
436. ORIENT DISTRICT, DEVELOPMENTS IN THE. *Sharpe, Bert M.*
M. W., vol. 30, May 8, 1909, p. 883.
A description of the district and of some of the mining properties.
437. CHEWELAH MINING DISTRICT, THE.
N. W. M. N., vol. 2, no. 6, May 1908, p. 120.
A description of development work by various companies.
438. NORTHPORT AND ITS MINES.
N. W. M. N., vol. 3, no. 2, July 1908, p. 35.
A history and description of the district and of some of the producers.
439. ORIENT DISTRICT, STEVENS COUNTY. *Armstrong, L. K.*
N. W. M. N., vol. 4, no. 3, Feb. 1909, p. 59.
A description of the district and of some of its producers.
440. DEERTRAIL MINING DISTRICT, STEVENS COUNTY. *Stiles, A. H.*
N. W. M. N., vol. 8, no. 2, Nov. 1912, p. 15.
A brief description of the ores and workings.
441. ORIENT MINING DISTRICT. *Armstrong, L. K.*
N. W. M. & M., vol. 9, no. 3, June 1913, p. 23.
A description of the topography, etc., and of some of the mines and workings.
442. GEOLOGY AND MINERAL RESOURCES OF STEVENS COUNTY.
Weaver, C. E.
W. G. S., Bull. —, 1918. In preparation.
An account of the areal, structural and economic geology of the county.
Describes ore deposits and 512 mines and prospects.
See also 12, 20, 21, 29, 37, 38, 43, 183.

Antimony

443. *TWENTY-EIGHT MILES SOUTH OF KETTLE FALLS.
M. & S. P., vol. 94, no. 7, Feb. 16, 1907, p. 201.

Arsenic

See 29.

Bismuth

444. *BISMUTH AND SILVER.

M. & S. P., vol. 64, no. 17, Apr. 23, 1892, p. 299.

Ledge 18 ft. wide reported in Bulldog mine, 7 miles west of Chewelah.

See also 29, 465, 480.

Chromium

See 38.

Copper

445. LUCKY BILL MINE, 4½ MILES EAST OF NORTHPORT.

M. & S. P., vol. 94, no. 7, Feb. 16, 1907, p. 201.

*Native copper discovered in the vein.

446. NOBLE FOUR GROUP, 2 MILES SOUTH OF BOSSBURG.

M. & S. P., vol. 102, no. 14, Apr. 8, 1911, p. 511.

*Ore runs 13 per cent copper, carries lead, silver, gold.

447. SUPERIOR MINES, NEAR BROWN'S LAKE, CHEWELAH DISTRICT.

M. & S. P., vol. 105, no. 17, Oct. 26, 1912, p. 545.

*Grey copper deposit.

See also 29, 37, 43, 70, 71, 461, 472, 38.

Gold

See 29, 37, 38, 43, 87, 446, 461, 472.

Iron

448. IRON ORES OF THE WESTERN UNITED STATES AND CANADA.

Leith, Charles Kenneth.

U. S. G. S., Bull. 285, 1906, pp. 194-200.

Gives geological relation and origin of the ores of Valley, and near Deep Creek Lake, southeast of Northport.

449. VALLEY DEPOSIT.

M. & S. P., vol. 85, no. 6, Aug. 9, 1902, p. 81.

*Iron deposit carrying 68 per cent iron.

450. VALLEY DEPOSITS.

M. & S. P., vol. 86, no. 18, May 2, 1903, p. 290.

*High grade hematite deposit 10 miles east of Valley.

451. CLUGSTON DISTRICT.

M. & S. P., vol. 87, no. 2, July 11, 1903, p. 30.

*Iron mines in Clugston district, 12 miles east of Bossburg. Ore is ilmenite, carrying 46 per cent iron, with some hematite.

452. O'TOOLE MOUNTAIN DEPOSIT.

M. & S. P., vol. 88, no. 4, Jan. 23, 1904, p. 70.

*Hematite.

See also 38, 43, 97, 98.

Lead

453. THE ELECTRIC POINT MINE IN WASHINGTON. *Lakes, Arthur.*

M. & E. W., vol. 45, no. 24, Dec. 9, 1916, p. 991, 1½ pp. illustrated.

Brief description of geology and ore bodies.

454. *RICH GALENA DEPOSIT. DISCOVERED AT ELECTRIC POINT MINE,
NEAR NORTHPORT.

M. & S. P., vol. 111, no. 17, Oct. 23, 1915, p. 647.

455. A BRIEF DESCRIPTION OF THE ORE BODIES OF THE ELECTRIC POINT MINE.

A. & N. W. M. J., vol. 21, no. 3, Mar. 18, p. 62, $\frac{1}{2}$ column.
See also 29, 37, 38, 43, 446, 461, 465, 472, 480.

Molybdenum

456. *CLAIMS EAST OF BOSSBURG.

M. & S. P., vol. 91, no. 25, Dec. 16, 1905, p. 421.

457. *IN POCKETS IN NORTHEASTERN PART OF THE COUNTY.

M. & S. P., vol. 95, no. 2, August 13, 1907, p. 49.

458. *AT PROPERTY OF MOLYBDENUM MINE & MILLING CO., NEAR IONE.

M. & S. P., vol. 112, no. 11, March 11, 1916, p. 387.
See also 99.

Nickel

459. *DISCOVERED AT HEAD OF CEDAR CANYON.

E. & M. J., vol. 58, no. 5, Aug. 4, 1894, p. 111.

460. *DISCOVERED ON MOSE CLAIM, 3 MILES SOUTH OF NORTHPORT; WITH TIN.

M. W., vol. 23, no. 15, Oct. 14, 1905, p. 429.

Silver

461. *SILVER-LEAD DEPOSIT RICH IN CARBONATES, CARRYING ALSO COPPER AND GOLD. ON HUNTER CREEK.

M. & S. P., vol. 69, no. 9, Sept. 1, 1894, p. 138.
See also 29, 37, 38, 43, 433, 444, 446, 472.

Tin

462. *IN TUNGSTEN KING MINE, DEER PARK.

M. & S. P., vol. 99, no. 26, Dec. 25, 1909, p. 871.
See also 460.

463. NOTES ON TUNGSTEN DEPOSITS NEAR DEER PARK, WASHINGTON.

Bancroft, Howland C.

U. S. G. S., Bull. 430, 1910, pp. 214-216.

Gives exact location of properties, topography of the adjoining country, age and character of the adjacent rocks, and analyses of tungsten minerals.

464. *NOTES ON OPERATIONS IN STEVENS COUNTY.

U. S. G. S., Min. Res. of U. S., 1910, p. 739 (Part I).

Tungsten

465. TUNGSTEN MINERALS AND DEPOSITS. *Hess, F. L.*

U. S. G. S. Bull. 652, 1917.

Mentions wolframite, ferri-tungstite and hubnerite in Washington. Gives illustrations of wolframite in pegmatite from Blue Grouse Mountains (p. 38), and of hubnerite in quartz mica schist from Tungsten King mine, Deer Park. Notes occurrence of cosalite (bismuth-lead sulphide) associated with hubnerite near Loon Lake, Stevens County (p. 47).

466. ROSELLE MINING CO.
M. & S. P., vol. 90, no. 11, March 18, 1905, p. 176.
*Wolframite at this property in the southern part of the county.
467. *AT CEDAR CANYON AND DEER TRAIL CAMPS.
M. & S. P., vol. 90, no. 19, May 13, 1905, p. 309.
468. ROSELLE MINING CO., AT ROSELLE CAMP, AND C. S. PALMER
PROPERTY AT DEER TRAIL.
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*Notes on the occurrence of tungsten.
469. *AT YOUNG TUNGSTEN MINES, SOUTH OF DEER TRAIL.
M. & S. P., vol. 93, no. 16, Oct. 20, 1906, p. 469.
470. *IN CEDAR CANYON CAMP.
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471. *TWO VEINS DISCOVERED NEAR SPRINGDALE.
M. & S. P., vol. 96, no. 11, March 14, 1908, p. 344.
472. *TUNGSTEN DISCOVERED IN THE SUPERIOR COPPER MINE, 6 MILES
WEST OF CHEWELAH. ASSOCIATED WITH GOLD, SILVER, COP-
PER, LEAD.
M. & S. P. vol. 99, no. 12, Sept. 18, 1909, p. 379.
473. *AT LOON LAKE. BLUE GROUSE TUNGSTEN CO.
M. & S. P., vol. 101, no. 15, Oct. 8, 1910, p. 489.
474. TUNGSTEN DEPOSITS OF STEVENS COUNTY. *Armstrong, L. K.*
M. & S. P., vol. 102, no. 22, June 3, 1911, p. 753.
A description of the location and occurrences of the ore. Gives analysis.
475. NEW DISCOVERY AT LOON LAKE.
M. & S. P., vol. 103, no. 22, Nov. 25, 1911, p. 698.
476. TUNGSTEN MINES NEAR SPOKANE.
M. & S. P., vol. 105, no 6, Aug. 10, 1912, p. 178, 1½ columns.
Brief description of the hubnerite deposit of the Tungsten Consolidated
Companies, near Loon Lake, on Blue Grass Mountain. Plans for work-
ing. Milling experiments.
477. *AT LAFAYETTE TUNGSTEN CO. PROPERTY, 40 MILES NORTH OF
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M. & S. P., vol. 111, no. 24, Dec. 11, 1915, p. 909.
478. TUNGSTEN ORE IN WASHINGTON. *Wolf, August.*
M. & S. P., vol. 31, no. 5, December, 1910, p. 307, 1½ pp.
A description of the development of the ore bodies, and concentration
processes of the Germania, Tungsten King, and Blue Grouse properties.
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Bancroft, Howland.
M. W., vol. 33, August 6, 1910, p. 234.
Abstract from U. S. G. S., Bull. 430 D.
480. TUNGSTEN DEPOSIT AT DEER PARK, WASHINGTON.
Bancroft, Howland.
N. W. M. N., vol. 7, no. 1, Feb. 1911, p. 9.
A description of a deposit of hubnerite and cosalite near Loon Lake.

481. TUNGSTEN IN WASHINGTON. *Wolf, August.*

N. W. M. J., vol. 9, no. 4, Dec. 1910, p. 39.

Description of the ore bodies, development, and treatment at Germanla, Tungsten King, and Blue Grouse properties.

See also 29, 43.

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482. *REPORTED ON O'TOOLE MOUNTAIN, 12 MILES FROM BOSSBURG.

M. & S. P., vol. 86, no. 6, Feb. 7, 1903, p. 95.

Associated with other minerals.

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483. *IN GREAT WESTERN MINE, 7 MILES SOUTHEAST OF NORTHPORT.

M. & S. P., vol. 112, no. 1, Jan. 1, 1916, p. 27.

See also 29, 37, 344.

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484. *VEIN 5 FT. WIDE, 8 MILES EAST OF CHEWELAH.

M. & S. P., vol. 97, no. 4, July 25, 1908, p. 111.

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485. *DEPOSIT DISCOVERED NEAR MARCUS, 5 MILES FROM COLVILLE RIVER.

E. & M. J., vol. 62, no. 3, July 18, 1896, p. 63.

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486. *AT MILL CREEK, 12 MILES EAST OF WALLA WALLA.

M. & S. P., vol. 94, no. 19, May 11, 1907, p. 584.

Article questions authenticity of deposit.

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Articles of a general character

487. MT. BAKER MINING DISTRICT, THE. *Smith, Geo. Otis.*

E. & M. J., vol. 73, March 15, 1902, p. 379.

A description of the geologic features and of the ore bodies of the Lone Jack mine, and other properties.

488. SLATE CREEK DISTRICT.

M. & S. P., vol. 90, no. 6, Feb. 4, 1905, p. 78.

*Summary of operations in the district.

489. *REPORT ON OPERATIONS IN THE COUNTY.

M. & S. P., vol. 91, no. 1, July 1, 1905, p. 16.

490. MT. BAKER DISTRICT, WASHINGTON. *McCarty, Morris.*

M. & E. W., vol. 45, no. 18, Oct. 28, 1916, p. 745, 1 p.

A brief description of the district and of the principal mines.

491. MINERAL RESOURCES OF WHATCOM COUNTY. *Phoenix, Chas. E.*

P. M. J., vol. 2, no. 2, Feb. 1913, p. 1, 2 pp.

A description of the coal and metal deposits, and a map of the county, describing particularly the Mt. Baker gold district. Gives details of the following mines:— Lone Jack or Post-Lambert; Great Excelsior; First Chance.

See also 12, 20, 37, 43.

Arsenic

See 43.

Copper

See 37, 43, 503.

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492. FREE MILLING GOLD DISTRICT OF WHATCOM COUNTY, WASHINGTON. *Adair, J. B.*

N. W. M. J., vol. 2, no. 2, Aug. 1906, p. 22, 3½ pp., map.

A description of the geographic position, geology, topography, ore deposits, and transportation of the Slate Creek district. Gives detailed description of the following properties: Chancellor group; Becker group; Eureka group; Mill Creek mine; Minnesota mine.

493. HAMMOND MINING CO. *Bailey, H. W.*

A. & N. W. M. J., vol. 5, no. 3, Sept. 1914, p. 51, 2½ pp. Illustrated.

A report on this property in northern Whatcom county. Describes ore bodies, development, and milling equipment.

494. *RICH PLACERS ON SKOOKUM CREEK, A BRANCH OF THE NOOKSACK RIVER.

E. & M. J., vol. 64, no. 26, Dec. 25, 1897, p. 769.

495. *RUBY CREEK PLACERS.

E. & M. J., vol. 68, no. 27, Dec. 30, 1899, p. 801.

Description of extension of hydraulic plant.

496. *DISCOVERY IN BEACH SANDS, NEAR MOUTH OF NOOKSACK RIVER, NEAR BLAINE.

E. & M. J., vol. 70, no. 1, July 7, 1900, p. 21.

497. *FREE MILLING GOLD DISCOVERED ON SKAGIT RIVER IN NORTHERN WHATCOM COUNTY.

E. & M. J., vol. 90, no. 24, Dec. 10, 1910, p. 1180.

498. *PLACERS ON THE UPPER SKAGIT.

M. & S. P., vol. 64, no. 17, Apr. 23, 1892, p. 299.

Notes difficulty of access.

499. *DISCOVERY ON THE LINE BETWEEN OKANOGAN AND WHATCOM COUNTIES IN THE CASCADES.

M. & S. P., vol. 69, no. 9, Sept. 1, 1894, p. 138.

M. & S. P., vol. 69, no. 10, Sept. 8, 1894, p. 154.

500. *RICH GOLD DISCOVERED IN DECOMPOSED QUARTZ ON EUREKA CLAIM, SLATE CREEK DISTRICT.

M. & S. P., vol. 70, no. 7, Feb. 16, 1895, p. 106.

501. SLATE CREEK CAMP, WASHINGTON.

M. & S. P., vol. 86, no. 19, May 9, 1903, p. 305, 1½ columns.

A description of the transportation features, geologic formations, workings, and ore bodies of this district near the summit of the Cascades in the northeast corner of the county. Free gold and telluride ores associated with lead and zinc.

502. *POST-LAMBERT MINE, MT. BAKER DISTRICT.

M. & S. P., vol. 87, no. 9, Aug. 29, 1903, p. 140.

Description of occurrence of free gold and tellurides, Describes workings briefly.

503. *MT. BAKER DISTRICT.

M. & S. P., vol. 87, no. 17, Oct. 24, 1903, p. 278.

Gold, silver, copper. 3½ miles from Shuksan.

504. *SLATE CREEK DISTRICT.

M. & S. P., vol. 87, no. 23, Dec. 5, 1903, p. 378.

Gold properties

505. *GOLD MINE ON SUMAS MOUNTAIN, NEAR NOOKSACK. (NOOKSACK MINING Co.)

M. & S. P., vol. 88, no. 15, Apr. 2, 1904, p. 237.

506. *PLACER GOLD DISCOVERED ON SUMAS MOUNTAIN.

M. W., vol. 26, no. 13, March 3, 1907, p. 434.

See also 37, 43, 491.

Lead

507. *GALENA CARRYING SILVER DISCOVERED ON HOKATUM RIVER JUST NORTH OF BAKER LAKE.

E. & M. J., vol. 54, no. 14, Oct. 1, 1892, p. 328.

See also 43, 501.

Molybdenum

508. *IN CASTLEMAN MINE, MT. BAKER DISTRICT.

E. & M. J., vol. 68, no. 27, Dec. 30, 1899, p. 800.

See also 43.

Nickel

509. *DISCOVERED IN MT. BAKER DISTRICT.

A. & N. W. M. J., vol. 10, no. 3, March 1917, p. 84.

See also 43.

Silver

See 37, 43, 503, 507.

Thallium

See 43.

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Zinc

See 37, 43, 501.

Graphite

See 38.

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510. BRIEF ACCOUNT OF OPAL DEPOSIT NEAR WHELAN, IN THE VICINITY OF COLFAX.
U. S. G. S., Min. Res. of U. S., 1892, p. 776.
511. DESCRIPTION OF OPAL DEPOSIT AND WORKINGS IN THE STATE OF WASHINGTON 5 MILES NORTHWEST OF MOSCOW, IDAHO.
U. S. G. S., Min. Res. of U. S., 1910, p. 874 (Part II).
512. AN ACCOUNT OF THE DISCOVERY OF OPALS IN BASALT NEAR WHELAN, 20 MILES SOUTHWEST OF COLFAX.
Min. Ind., vol. 1, 1892, p. 401.
513. OPALS OF FINE VARIETY AND COLOR DISCOVERED NEAR THE WASHINGTON-IDAHO BOUNDARY LINE, NEAR MOSCOW, IDAHO. IN BASALT MATRIX.
M. & S. P., vol. 62, no. 4, Jan. 24, 1891, p. 56.
514. *DEPOSIT IN BASALT AND CLAY FORMATION IN WHITMAN COUNTY.
E. & M. J., vol. 54, no. 5, July 30, 1892, p. 112.
(North American Gem Opal Mining Co.)
515. FIRE OPAL IN A BASALT IN WASHINGTON. *Kunz, Geo. Frederick*.
Geologic Society of America, vol. 2, p. 639, $\frac{1}{2}$ p.
Account of discovery of deposit near Whelan. In altered and unaltered basalt.

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See 20, 31.

Gold

516. *PLACER DEPOSIT, ONE MILE FROM MOUTH OF AMERICAN RIVER.
M. & S. P., vol. 67, no. 7, Aug. 12, 1893, p. 110.
517. FROM BEAR GAP.
M. & S. P., vol. 95, no. 26, Dec. 28, 1907, p. 801.
*Ore from Bear Gap "may contain \$8.00 per pound in gold."
518. GOLD AND SILVER.
E. & M. J., vol. 92, no. 27, Dec. 23, 1911, p. 1248.
*Discovered within two miles of North Yakima.
See also 519.

Iron

519. *IRON, GOLD, SILVER, AND LEAD DISCOVERED ON A PROSPECTING TRIP IN THE MT. ADAMS DISTRICT.
M. & S. P., vol. 61, no. 4, July 26, 1890, p. 53.

Lead

See 519.

Silver

See 518, 519.

Tungsten

520. *DISCOVERED NEAR BUMPING LAKE.

A. & N. W. M. J., vol. 8, no. 2, Feb. 1916, p. 46.

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521. *NEAR COWLITZ PASS. IVANHOE MINING CO. SAID TO ASSAY
40 PER CENT ZINC.

M. & S. P., vol. 94, no. 17, Apr. 27, 1907, p. 522.

Gem Onyx

522. *DISCOVERED NEAR NORTH YAKIMA.

E. & M. J., vol. 51, no. 8, Feb. 21, 1891, p. 244.

ARTICLES DEALING WITH METALLURGICAL PLANTS AND PROCESSES

Article of a general character

523. NOTES ON THE TREATMENT OF ARSENICAL ORES. *Lee, Chester F.*

N. W. M. J., vol. 3, no. 1, Jan. 1907, p. 1, 1 p.

A discussion of the possibilities of treatment of these ores of the Cascade Mountains.

CHELAN COUNTY

See 37.

FERRY COUNTY

524. THE NEW REPUBLIC MILL AT REPUBLIC, WASHINGTON.

E. & M. J., vol. 70, Dec. 1, 1900, p. 638.

Description of mill for reduction by roasting and cyaniding.

525. TREATMENT PROBLEM OF REPUBLIC, WASHINGTON, ORES.

Cirkel, Fritz.

E. & M. J., vol. 85, Feb. 1, 1908, p. 267.

An account of different methods of cyanide treatment and of the mill failures.

526. CYANIDING THE ORES OF REPUBLIC, WASHINGTON.

Megraw, Herbert E.

E. & M. J., vol. 95, no. 17, Apr. 16, 1913, pp. 835-838.

An article dealing with the unusual problem of exceedingly hard rock and minute particles of gold, and the methods used in solving the difficulties.

527. *A DESCRIPTION OF THE GOLD REDUCTION PROCESS IN THE MILLS
OF THE REPUBLIC EXPLORATION AND CYANIDE CO., AND THE
REPUBLIC REDUCTION CO.

Min. Ind., vol. 9, 1900, p. 326.

528. AN ACCOUNT OF THE CYANIDE PROCESS OF THE REPUBLIC POWER
AND CYANIDE CO. *Jackling, D. C.*

Min. Ind., vol. 10, 1901, p. 345, 2 pp.

529. *GRINDING PRACTICE IN THE MILLS OF THE NORTH WASHINGTON POWER AND REDUCTION CO., AND THE SAN POIL MILL, REPUBLIC.
Min. Ind., vol. 22, 1913, p. 814.
530. WASHINGTON POWER AND REDUCTION CO. MILL AT REPUBLIC, WASHINGTON. *Newton, H. W.*
M. W., vol. 34, Feb. 25, 1911, p. 447.
A detailed description of the cyanide mill.
531. MOUNTAIN LION MILL.
M. & S. P., vol. 80, no. 13, March 31, 1900, p. 351.
An account of the opening of the plant and description of ore treatment.
532. REPUBLIC SAMPLING AND REDUCTION WORKS. *Jackling, D. C.*
M. & S. P., vol. 81, no. 13, Sept. 29, 1900, p. 372.
A description of the plant of the Republic Consolidated Gold Mining Co.
533. NORTH WASHINGTON POWER AND REDUCTION MILL.
Joseph, M. H.
M. & S. P., vol. 103, July 8, 1911, p. 43.
A description of the mill processes and a flow sheet.
534. SAN POIL CONSOLIDATED MINING CO., NEW MILL OF.
M. & S. P., vol. 105, no. 1, July 6, 1912, p. 29.
Description of machinery of the plant.
535. MINING AND MILLING AT REPUBLIC. *Morse, E. C.*
M. & S. P., vol. 109, Sept. 19, 1914, p. 412, 5 pp.
A detailed description of the rejuvenation of Washington's most important gold mining district. Figures covering capacity, operating, construction and repair costs of the new Williams crusher. Flow sheet of the San Poil mill.
536. NORTHERN WASHINGTON POWER AND REDUCTION CO.'S MILL AT REPUBLIC, WASHINGTON. *Newton, H. W.*
N. W. M. N., vol. 7, no. 1, Feb. 1911, p. 4.
A discussion of the metallurgy of the ores of the district, and description of the proposed mill.
537. ORE TREATMENT AT REPUBLIC, WASHINGTON.
Thomson, Francis A.
T. A. I. M. E., 1912, vol. 43, p. 672.
History and production, geology, ore treatment, and mill flow sheets.
538. THE SAN POIL MILL, REPUBLIC, WASHINGTON. *Morse, Edward C.*
T. A. I. M. E., 1912, vol. 43, p. 697.
Description and flow sheet.
See also 21, 29, 37, 166, 172, 174, 175, 176, 178, 183, 191, 199.

KITTITAS COUNTY

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LEWIS COUNTY

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OKANOGAN COUNTY

539. METALLURGICAL TREATMENT OF OKANOGAN ORES.

Thomson, Francis A.

A. & N. W. M. J., vol. 8, no. 2, Feb, 1916, p. 28, 1½ pp.

A report of progress in research work on these complex lead-zinc-copper-antimony ores.

540. OKANOGAN COUNTY METALLURGY.

M. & S. P., vol. 112, no. 2, Jan. 8, 1916, p. 68, ½ column.

Suggestions for the treatment of the complex lead and zinc ores of this county.

541. PALMER MOUNTAIN MILL.

E. & M. J., vol. 82, no. 23, Dec. 8, 1906, p. 1080, 2¼ pp. Illustrated.

Description and transverse section of stamp mill and cyanide plant of the Palmer Mountain Tunnel and Power Co.

See also 37, 293.

PIERCE COUNTY

542. PRECIPITATING FUME AT PLANT OF TACOMA SMELTING COMPANY.

Roberts, Milnor.

A. & N. W. M. J., vol. 8, no. 3, March 1916, pp. 49-50. Illustrated.

A description of the process and apparatus employed.

See also 37.

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543. BUNKER HILL MINE AT REITER NEAR INDEX.

M. & S. P., vol. 97, no. 4, July 25, 1908, p. 111.

*Smelter to make blister copper blown in.

544. BUNKER HILL MINE.

M. & S. P., vol. 90, no. 10, March 11, 1905, p. 160.

*Note on the completion of the concentrator. Brief description of machinery.

545. PUGET SOUND REDUCTION CO. PLANT AT EVERETT.

U. S. G. S., Min. Res. of U. S., 1903, p. 328.

Description of plant for production of white arsenic.

546. MONTE CRISTO CONCENTRATOR.

E. & M. J., vol. 58, no. 10, Sept. 8, 1894, p. 231.

*Brief account of opening of the plant and description of machinery.

See also 354, 390.

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547. NORTHPORT SMELTER.

M. & S. P., vol. 112, Feb. 26, 1916, p. 325, ½ column.

Brief description of the rebuilt plant.

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MILLS AND METALLURGICAL PLANTS

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Arrastres (Slate Creek), Whatcom -----	37	Palmer Mountain Mill, Okanogan -----	541
Arrastres (Swauk), Kittitas -----	37	Port Townsend Smelter (Irondale) Jefferson -----	224
Arsenic Plant, Mineral, Lewis -----	271	Puget Sound Reduction Co. (Everett Smelter) -----	545
Black Bear Mill, Okanogan -----	37	Republic Consolidated Gold Mining Co., Ferry -----	532
Blewett Mill, Pashastin, Chelan -----	37	Republic Exploration and Cyanide Co., Ferry -----	527
Blue Grouse Mill, Stevens -----	476, 481	Republic Metallurgy (general) -----	174, 175, 176, 178, 183
Bunker Hill Mill, Snohomish -----	354	Republic Mill, Ferry -----	29, 37
(see Copper Bell)		Republic Mill, New, Ferry -----	524
Copper Bell Mill, Snohomish -----	354	Republic Power and Cyanide Co., Ferry -----	528
Eureka Mill, Whatcom -----	37	Republic Reduction Co., Ferry -----	527
Everett Smelter, Snohomish -----	37, 545	Republic Sampling and Reduction Works, Ferry -----	532
Germania Mill, Stevens -----	29, 478, 481	Ruby Mill, Okanogan -----	37
Golden Zone Mill, Okanogan -----	37	San Poll Mill, Ferry -----	529, 535, 538
Great Excelsior Mill, Whatcom -----	37	San Poll Consolidated Mill, Ferry -----	534
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Ivanhoe Mill, Okanogan -----	37	Tacoma Smelting Co., Pierce -----	37, 542
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Morton Quicksilver Plant, Lewis -----	278	Wauconda Mill, Okanogan -----	37
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Part VII

FINDING LIST OF THE MINERAL PRODUCTS NOTED IN THE BIBLIOGRAPHY

In this finding list of the mineral products noted in the bibliography the metallic products are arranged in alphabetical order, followed by such non-metallic products as are listed in the bibliography, also in alphabetical order.

Under each product are noted the counties under which references to that particular product are listed.

The following list of counties noted in the bibliography shows the initial number of the references under each county:

Chelan	104	Lincoln	281
Clallam	150	Mason	285
Clark	153	Okanogan	288
Cowlitz	155	Pacific	338
Douglas	159	Pend Oreille	399
Ferry	161	Pierce	345
Franklin	208	San Juan	351
Garfield	210	Snohomish	359
Grant	211	Skagit	395
Grays Harbor...	213	Skamania	415
Jefferson	220	Spokane	416
King	228	Stevens	433
Kitsap	236	Walla Walla.....	486
Kittitas	237	Whatcom	487
Klickitat	268	Whitman	510
Lewis	269	Yakima	516

METALLIC PRODUCTS

ALUMINUM

Chelan.

ANTIMONY

Ferry, King, Kittitas, Okanogan, Snohomish, Stevens.

ARSENIC

Ferry, King, Lewis, Okanogan, Snohomish, Skagit, Stevens, Whatcom.

BISMUTH

Stevens.

COBALT

Chelan, Ferry.

CHROMIUM

Snohomish, Skagit, Stevens.

COPPER

Chelan, Clark, Cowlitz, Ferry, Jefferson, King, Kittitas, Lewis, Lincoln, Mason, Okanogan, Pend Oreille, Pierce, Snohomish, Skagit, Skamania, Stevens, Whatcom.

GOLD

Chelan, Clallam, Clark, Cowlitz, Douglas, Ferry, Franklin, Grays Harbor, Jefferson, King, Kittitas, Klickitat, Lewis, Okanogan, Pacific, Pend Oreille, Pierce, San Juan, Snohomish, Skagit, Skamania, Spokane, Stevens, Whatcom, Yakima.

IRIDIUM

Clallam, Okanogan, Skagit.

IRON

Chelan, Clallam, Ferry, Franklin, Grays Harbor, Jefferson, King, Kittitas, Mason, Okanogan, San Juan, Snohomish, Skagit, Stevens, Yakima.

LEAD

Chelan, Ferry, Garfield, King, Kittitas, Lewis, Lincoln, Okanogan, Pend Oreille, Snohomish, Skagit, Skamania, Spokane, Stevens, Whatcom, Yakima.

MANGANESE

Grays Harbor, Jefferson, Mason.

MOLYBDENUM

Chelan, Ferry, King, Okanogan, Pend Oreille, Pierce, Snohomish, Skagit, Stevens, Whatcom.

NICKEL

Chelan, Clallum, Ferry, Kittitas, Lewis, Okanogan, Skagit, Stevens, Whatcom.

OSMIUM

Clallam, Skagit.

PLATINUM

Chelan, Clallum, Clark, Okanogan, Skagit.

QUICKSILVER

Chelan, Cowlitz, Kittitas, Lewis, Snohomish.

SELENIUM

Ferry.

SILVER

Chelan, Clark, Ferry, Garfield, Jefferson, King, Kittitas, Lewis, Lincoln, Okanogan, Pend Oreille, Pierce, Snohomish, Skagit, Skamania, Spokane, Stevens, Whatcom, Yakima.

THALLIUM

Whatcom.

TIN

Chelan, Kitsap, Snohomish, Spokane, Stevens, Walla Walla, Whatcom.

TUNGSTEN

Ferry, Okanogan, Spokane, Stevens, Yakima.

URANIUM

Snohomish, Stevens.

VANADIUM

Chelan.

ZINC

Ferry, King, Okanogan, Pend Oreille, Snohomish, Skagit, Spokane, Stevens, Whatcom, Yakima.

NON-METALLIC PRODUCTS

ASBESTOS

Okanogan, Skagit, Stevens.

BORAX

Grant.

CERIUM

Chelan.

GEM ONYX

Yakima.

GRAPHITE

Chelan, Lewis, Pierce, Skagit, Spokane, Stevens, Whatcom.

MAGNESIUM SULPHATE

Okanogan.

MARIPOSITE (chromium mica).

Okanogan.

MICA

Chelan, Douglas, Skagit, Spokane, Stevens.

MINERAL PAINT

Kittitas.

OPAL

Lincoln, Whitman.

POTASH

Okanogan.

RUBIES

Douglas.

SILICA

Kittitas, Spokane.

SODIUM SULPHATE

Grant, Okanogan.

STRONTIUM

Skagit.

SULPHUR

Lewis.

TALC

Lincoln, Skagit.

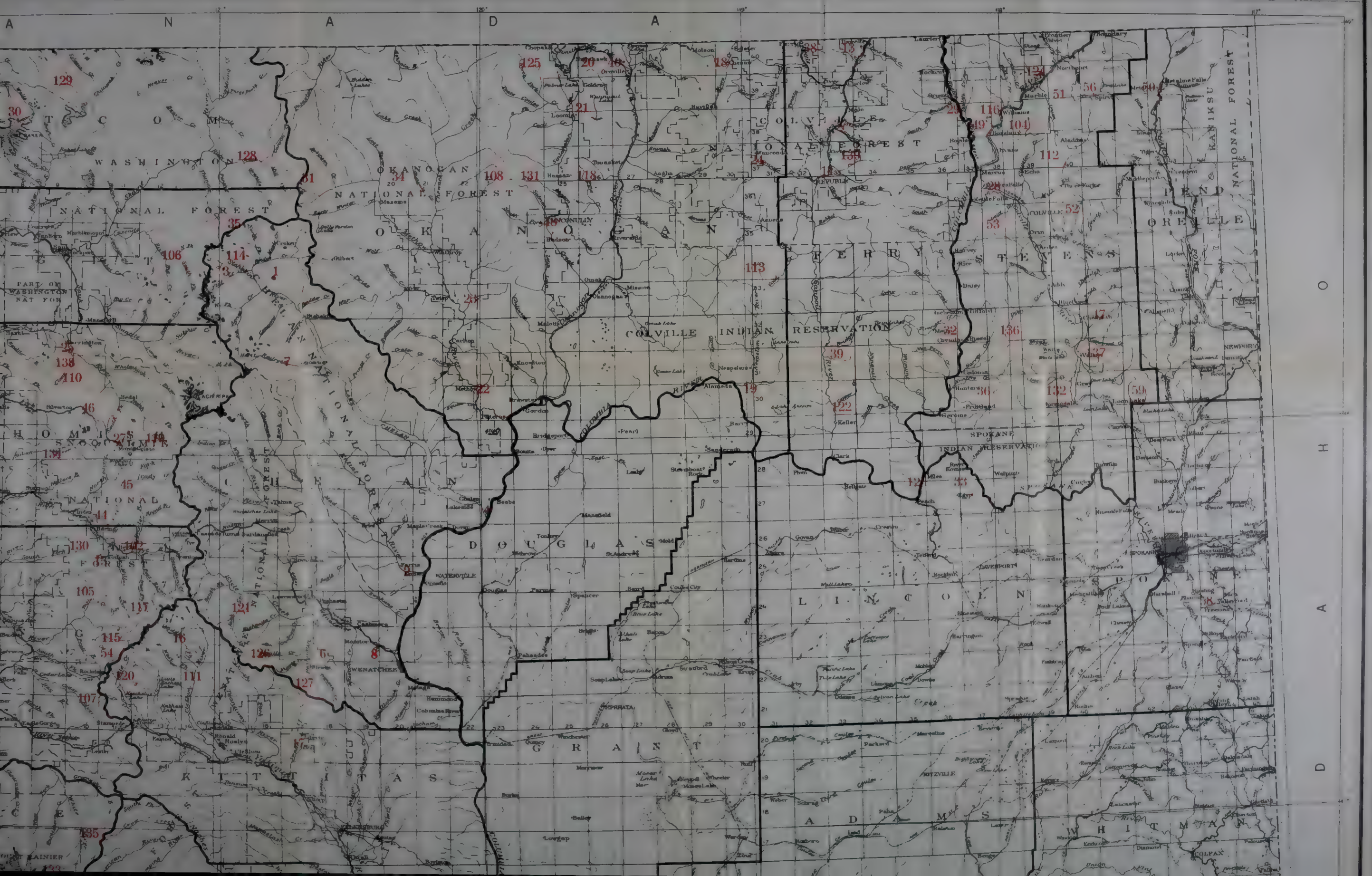
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METAL MINING DISTRICTS AND PRINCIPAL CAMPS IN THE STATE OF WASHINGTON

Map accompanying Bulletin 4 of the Engineering Experiment Station, University of Washington, entitled

A SUMMARY OF MINING AND METALLIFEROUS MINERAL RESOURCES IN THE STATE OF WASHINGTON

By Arthur Homer Fischer

Edited by Milnor Roberts, Dean of the College of Mines

Prepared under cooperative agreement between the College of Mines and the Northwest Station, United States Bureau of Mines. Data added by permission to map published by the United States Geological Survey. December, 1918.

- ★ SEATTLE
- PULLMAN
- RAILROAD
- RIVER
- HIGHWAY

Scale 1:500,000
0 10 20 30 Miles
0 10 20 30 Kilometers

ENGINEERING EXPERIMENT STATION UNIVERSITY OF WASHINGTON

ENGINEERING EXPERIMENT STATION SERIES

BULLETIN No. 5

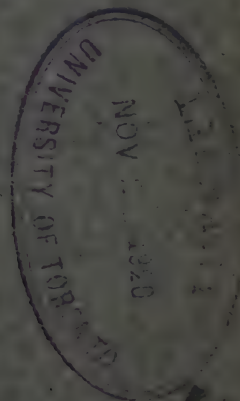
Electrometallurgical and Electrochemical Industry in the State of Washington

BY

CHARLES DENHAM GRIER

Fellow in Electrometallurgy at the College of Mines
And the Seattle Mining Experiment Station
United States Bureau of Mines

Prepared under co-operative agreement between the University of
Washington and the United States Bureau of Mines



SEATTLE, WASHINGTON
PUBLISHED BY THE UNIVERSITY
MARCH, 1920

THE Engineering Experiment Station of the University of Washington was established in December, 1917, in order to coördinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is twofold:—

- (a) To investigate and to publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural and industrial affairs.
- (b) To undertake extended research and to publish reports on engineering and scientific problems.

The control of the Station is vested in a Station Staff consisting of the President of the University, the Dean of the College of Engineering as ex-officio Director, and seven members of the Faculty. The Staff determines the character of the investigations to be undertaken and supervises the work. For administrative purposes the work of the Station is organized into seven divisions:—

1. Forest Products
2. Mining and Metallurgy
3. Chemical Engineering and Industrial Chemistry
4. Civil Engineering
5. Electrical Engineering
6. Mechanical Engineering
7. Physics Standards and Tests

The results of the investigations are published in the form of bulletins. Requests for copies of the bulletins and inquiries for information on engineering and industrial problems should be addressed to the Engineering Experiment Station, University of Washington, Seattle.

ENGINEERING EXPERIMENT STATION

UNIVERSITY OF WASHINGTON

ENGINEERING EXPERIMENT STATION SERIES

BULLETIN No. 5

Electrometallurgical and Electrochemical Industry in the State of Washington

BY

CHARLES DENHAM GRIER

Fellow in Electrometallurgy at the College of Mines and the Seattle
Mining Experiment Station United States
Bureau of Mines

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF

MASTER OF SCIENCE IN METALLURGICAL ENGINEERING

Prepared under co-operative agreement between the University of
Washington and the United States Bureau of Mines



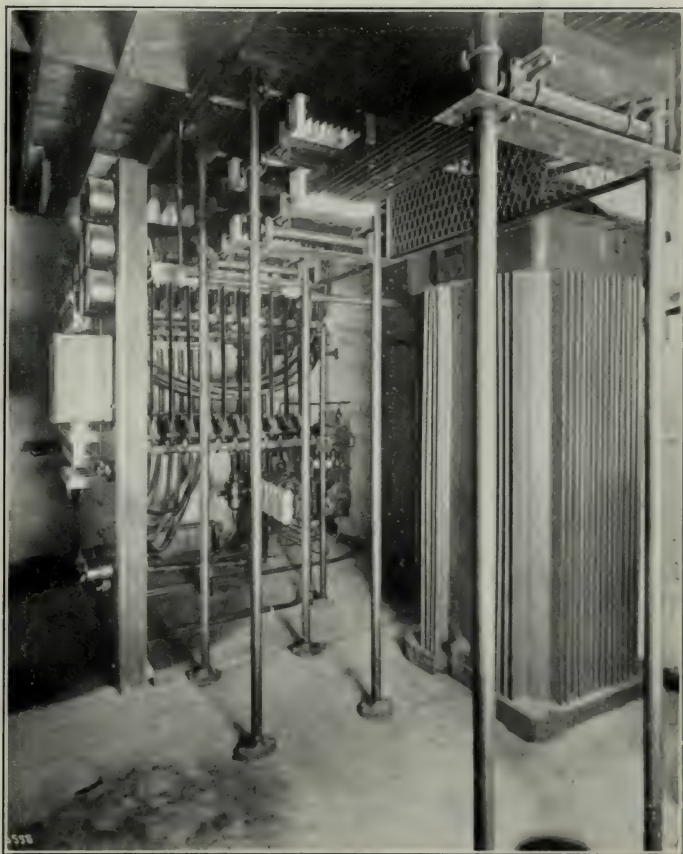
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SEATTLE MINING EXPERIMENT STATION,
UNITED STATES BUREAU OF MINES

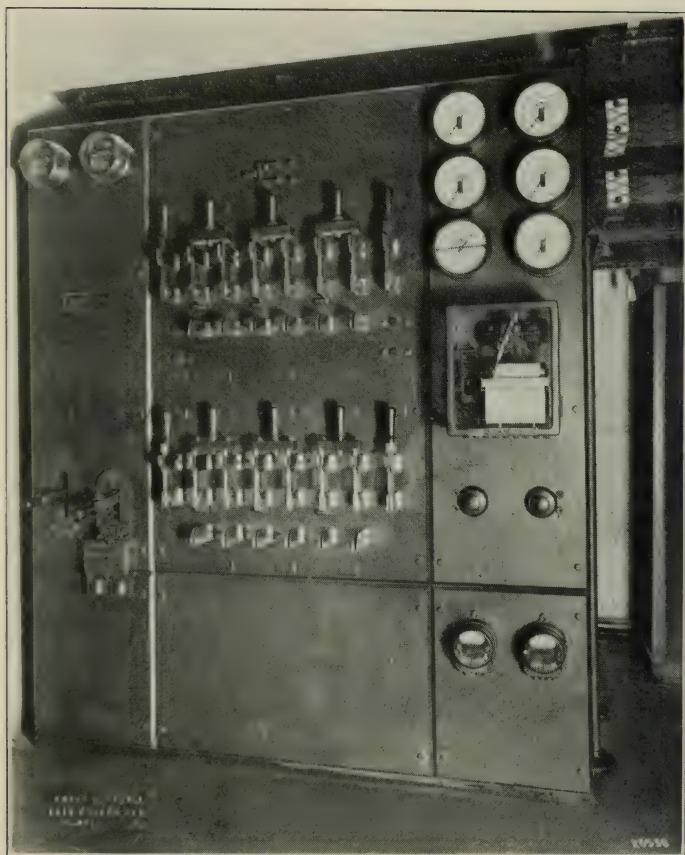


MINES HALL,
COLLEGE OF MINES, UNIVERSITY OF WASHINGTON



EQUIPMENT FOR SUPPLYING POWER FOR EXPERIMENTAL ELECTRIC FURNACES

Electrometallurgical Laboratory, Seattle Mining Experiment Station, United States Bureau of Mines, College of Mines, University of Washington



SWITCHBOARD FOR SUPPLYING POWER TO EXPERIMENTAL ELECTRIC FURNACES
Electrometallurgical Laboratory, Seattle Mining Experiment Station, United
States Bureau of Mines, College of Mines, University of Washington

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ELECTROMETALLURGICAL AND ELECTROCHEMICAL INDUSTRY IN THE STATE OF WASHINGTON

INTRODUCTION

One of the main lines of investigation assigned to the Seattle Mining Experiment Station of the United States Bureau of Mines was research in electrometallurgy. This is fitting work for a station situated in a state in which, according to the United States Geological Survey, one-sixth of the total potential water power of the entire country is concentrated. A large share of this power is within a short distance of deep water, so that ocean transportation would be available for electrometallurgical plants using this power. Moreover, as manufacturing on the Pacific coast, and trade between this country and the Orient gain in importance, growing markets for the products of such plants are opened up. It is undoubtedly true that in the future, although perhaps not the immediate future, large amounts of power will be used on the Pacific coast in electrometallurgical and electrochemical industry.

The first step in this investigation was a general survey of the status of, and opportunities for, electrometallurgical industry in the Pacific Northwest. Under the direction of Francis C. Ryan, electrometallurgist of the U. S. Bureau of Mines, the writer, as Research Fellow of the College of Mines, University of Washington, studied that part of the subject which relates to the State of Washington. The following pages result from this study.

The essential factors involved in electrometallurgical industries include the availability and cost of electric power, raw materials, and labor, and the difficulty and cost of marketing the products. A widespread impression prevails that cheap power is the only requirement for these industries. This is not true, for other factors have equal or greater importance. Cheap power is, however, of prime importance, and inasmuch as many ill-considered and conflicting statements have been made regarding the amount and cost of power available, a general discussion of present developments and of the factors which enter into the utilization of our water powers is first presented. Existing electrometallurgical and electrochemical industries in the state are next reviewed. This review is followed by a brief discussion of two electrometallurgical industries, intended to be illustrative examples of how various factors influence the possibility of establishing these industries in the State, rather than as finished studies of the subject.

In general the object of this paper is not so much to present a statement of detailed facts regarding the establishment of such industries as it is to make a general survey of the requirements of these industries in this State, in order to give the non-technical reader a better understanding of the whole matter, and to prepare the way for such detailed investigations as may in the future be found desirable.

DEVELOPED WATER POWER IN WASHINGTON

POWER DEVELOPED AND ITS RELATION TO ELECTROMETALLURGY

The development of the water powers of the State of Washington has not been influenced by consideration of its use in electrometallurgy. No plants have been built especially for this purpose. What little electrometallurgical industry now exists in the State, with the exception of the Tacoma copper refinery, which generates part of its power from the heat in waste gases, is furnished with power by plants designed and erected for the ordinary class of central station service.

Table I gives a list of the water power development in the State. It is compiled mainly from a thesis by E. J. Beery, submitted to the University of Washington in 1915, entitled, "Electrical Development in the State of Washington." It is believed that with one exception, no developments of importance have taken place since then. The results of personal inquiry supplemented the information obtained from this source.

The total water power developed is shown to be 254,755 kilowatts. By reference to Table II it will be noticed that, excluding the power used at the refinery of the smelter at Tacoma the power used in electrometallurgical and electrochemical industries now in operation is furnished by transformer installations totalling 12,365 kilovolt-amperes. The power required would be 11,000 kilowatts, or not quite four and one-half per cent of the developed water power. Excluding also the nitrogen fixation plant at Lagrande, the percentage is only three. It is obvious that compared with other kinds of loads, the present electrometallurgical and electrochemical load is unimportant.

POTENTIAL WATER POWER IN WASHINGTON

WATER POWER RESOURCES OF THE STATE

One of the most remarkable of Washington's natural assets is its abundance of potential water power. The heavy precipitation which is characteristic of Washington, and the steep slopes of the mountains causing it, result in a number of rivers of steep gradient and considerable flow which are possible of utilization for power generation. One remarkable and fortunate feature of Washington streams is that they often supplement each other. Thus one stream may be fed mainly from glacier and snow fields, and another may be fed from an area which does not store the moisture to a large extent either in the ground as ground storage, or in the form of snow or ice. The latter stream will have a good flow during the wet season and the former will have a small flow because the precipitation will be in the form of snow. In the dry, hot season, conditions will be reversed; the glaciers and snow fields will melt and furnish a good flow to the former stream, while the flow of the latter will be much reduced on account of the slight precipitation. The power of either stream alone would be subject to greater variations than would the sum of the

TABLE I

DEVELOPED WATER POWER IN THE STATE OF WASHINGTON

OWNERSHIP	Stream and Location	Rated Capacity of Generators KW.	Head Ft.
Puget Sound Traction, Light & Power Co.	North Fork, Nooksack River.	1,500	176
	Snoqualmie River at Snoqualmie Falls (2 plants). .	19,750	270 & 255
	White River at Dieringer.	52,600	440 - 480
	Puyallup River at Electron.	14,000	880
Washington Water Power Co.	Spokane River at Long Lake.	37,500	168
	Spokane River at Little Falls.	20,500	71
Spokane & Inland Empire Railroad	Spokane River above Spokane.	8,750	64 - 74
Pacific Power & Light Co.	Spokane River above Little Spokane River.	16,000	58 - 65
	Naches River near Naches.	3,750	151
	Walla Walla River near Walla Walla.	2,750	17
	Yakima River at Prosser.	600	28
	Touchee River at Waiilatburg.	150	38
	Naches River at North Yakima.	300	17
	White Salmon River at Housum.	75	82
	Tucannon River near Pomeroy.	150	300
	Klickitat River at Goldendale.	150	16 - 24
City of Spokane.	Spokane River above Spokane.	2,100	500
City of Seattle.	Cedar River below Cedar Lake.	10,500	380
	Lake Union, Seattle. Reservoir overflow.	1,500	420
	Nisqually River at La Grande.	20,000	172
	White Salmon River near mouth.	6,000	180
Northwestern Electric Co.	Wenatchee River in Tumwater Canon.	3,550	460
Great Northern Railway Co.	Sullivan Creek near mouth.	6,000	100
Inland Portland Cement Co.	Elwha River near Port Angeles.	1,500	465
Olympic Power Co.	Asotin Creek near Pomeroy.	400	444
Lewis-Clarkston Co.	Bear Creek.	1,200	51
Superior Portland Cement Co.	Yakima River near Ellensburg.	950	20 - 28
City of Ellensburg.	Columbia River at Priest Rapids.	1,800	35
Hanford Irrigation & Power Co.	Wenatchee River at Dryden.	1,050	764
Wenatchee Valley Gas & Electric Co.	Quiltee River near mouth.	150	78
	Leelanaw River near Tatlat.	960	81
Olympic Light & Power Co.	Deschutes River at Tumwater.	1,000	40
Washington Oregon Corporation	Kalama River near Kalama.	675	367
Tillamook Development Co.	Toots Conlee Creek near mouth.	450	78
Stevens County Electric Co.	Colville River near Colville.	420	24
North Washington Power Co.	Shookamoon River near Oroville.	350	25
Methow Power Co.	Methow River near Pateros.	180	..
Miscellaneous small plants	.....	3,515	..
	TOTAL DEVELOPED WATER POWER.	254,755 KW.	..

powers of both. If power developments were made on both streams by connecting them together, the two could furnish more continuous power than could they if each were operated independently.

This illustrates the necessity for specifying the basis on which the power of streams shall be estimated. "The amount of potential water power in the State of Washington," is a quantity that varies greatly according as different conditions are specified as bases for calculation. For this reason several estimates are discussed and compared.

BUREAU OF CORPORATIONS ESTIMATE OF POTENTIAL POWER

The first one, which has been given considerable publicity, is an estimate given in the "Report of the Commissioner of Corporations on Water Power Development in the United States."

This estimate is a modification, by the Bureau of Corporations, of one made by the United States Geological Survey in 1908 for the National Conservation Congress. The interpretation to be placed on this estimate is indicated by the survey in the following words: "For the purposes of this report it has been assumed that all the power in the United States will some day be required. Such an interpretation is the logical one when natural resources are being considered. In other words, the schedule here presented must be interpreted for the future rather than for the present. The reader should not assume that all the power here shown is economical or available today. Much of it, indeed, would be too costly in development to render it of commercial importance under the present conditions of market and the price of fuel power. The schedule shows, therefore, what will be the maximum possibilities in the day when our fuel shall have become so exhausted that the price thereof for production of power is prohibitive, and the people of the country shall be driven to the use of all the water power that can be reasonably produced by the streams."¹

Maximum and Minimum Power.—Two classes are given, called "minimum and maximum" power respectively. "The estimates for the minimum power . . . are not on the minimum flow for any day, or even on the lowest average for a very few consecutive days during the entire period covered, but are based on the averages of the minimum flow for the two lowest periods of seven consecutive days in each year for seven years, or less, according to the length of the period for which records were available."¹

"The assumed maximum development rests on quite a different basis. . . . It is based upon the continuous power indicated by the flow of a stream for the six months in the year (not necessarily six consecutive months) showing the highest flow."¹ From the flow dur-

¹ U. S. G. S. Water Supply Paper, 235, p. 47.

ing the lowest seven consecutive days in the months of high flow for each year, averaged for a period of seven years, or less, if the records covered less, the assumed maximum power was calculated.

Two values each for the minimum and maximum power are given, which result from using the figures 75 and 90 per cent for the efficiency of the water wheel. An efficiency of 90 per cent is not realized at the present time; the efficiency of a turbine, under test conditions, installed in the most modern plant in the State is 84 per cent. The figure of 75 per cent is said to approach the average efficiency actually obtained in all existing plants.

It should be emphasized that the "minimum" power is really the maximum continuous or all-year power which will be available in the future. It does not mean that it is the least but is, on the contrary, the most that can be expected in the future, for as observed before, the availability of much of the power will be possible only after many years have elapsed. However, it should also be borne in mind that these figures do not take into account the equalization of flow by means of storage, and that by use of storage, a considerable amount of power in the "maximum" class would be transferred to the class of continuous or "minimum" power by means of increasing the minimum flow.

The following table gives the figures for the State of Washington, for adjoining states, the mountainous western states (those whose drainage or part thereof flows to the Pacific Ocean), and the entire United States:

TABLE II
POTENTIAL WATER POWER IN THE PACIFIC STATES ²

	POTENTIAL HORSEPOWER			
	90% Basis		75% Basis	
	Minimum	Assumed Maximum	Minimum	Assumed Maximum
Washington	5,918,000	10,376,000	4,932,000	8,647,000
Oregon	3,777,000	7,935,000	3,148,000	6,613,000
California	4,109,000	9,382,000	3,424,000	7,818,000
Idaho	1,394,000	3,000,000	1,162,000	2,567,000
Montana	3,299,000	5,197,000	2,749,000	4,331,000
Western States	22,795,000	44,049,000	18,996,000	36,707,000
United States	32,083,000	61,678,000	26,736,000	51,398,000
Per cent. of power in United States situated in Washington	18.4	16.8	18.4	16.8

HARRIS' ESTIMATE OF POTENTIAL POWER

Another set of figures is that compiled in 1913 at the request of the Secretary of the State of Washington by C. W. Harris, Associate

² From Report of the Commissioner of Corporations on Water Power Development in the United States.

Professor of Civil Engineering at the University of Washington, and published in the "Homeseekers Guide" issued by the Bureau of Statistics and Immigration of the State of Washington in 1915. The figures assume the utilization of storage, and the development of the power on two bases. The first is the development of continuous power the entire twelve months of the year by all streams where development costs will not exceed a hundred and fifty dollars, i. e., the continuous power which it is practicable to develop at the present time. The second is the "estimated average per year irrespective of distribution or cost." This figure differs from the "assumed maximum" development estimated by the Bureau of Corporations in that it considers storage and is an average rather than maximum figure. It should be noted that the power of the Snake River is not included. The figures are as follows:

TABLE III

WATER POWERS OF THE STATE OF WASHINGTON

(From Preliminary Reconnaissance Notes Prepared by the Department of Engineering of the University of Washington)

	DRAINAGE AREA	H.P. Entire 12 months at cost of \$150 per H.P. or less	H.P. Estimated average for year irrespective of distribution or cost
1	Cowlitz River	230,000	1,500,000
2	Toutle River	48,000	320,000
3	Lewis River	55,000	450,000
4	White Salmon River	60,000	220,000
5	Nisqually River	45,000	225,000
6	Puyallup River	40,000	175,000
7	White River	110,000	285,000
8	Cedar River	75,000	200,000
9	Snoqualmie River	100,000	400,000
10	Skykomish River	85,000	240,000
11	Stillaguamish River	50,000	220,000
12	Skagit River	250,000	1,200,000
13	Klickitat River	118,000	300,000
14	Chelan River	300,000	500,000
15	Spokane River	80,000	240,000
16	The Olympics	160,000	350,000
17	Columbia River (with tributaries not mentioned)	750,000	5,800,000
	TOTAL	2,556,000	13,125,000

This estimate is interesting because it shows the concentration of power around Puget Sound. The availability of power within reach of ocean transportation should be a potent factor in the success of electro-chemistry in Washington, especially when the Oriental and Australian markets are better exploited.

JACKSON AND HOAR'S ESTIMATE

The only other independent estimate which was found was one in an abstract in the Journal of Electricity, Oct. 1, 1917, page 299, of a report by H. F. Jackson and F. Emerson Hoar to the California

State Council of Defense on the Use of Hydroelectric Power to Conserve Fuel Oil. Under the heading "Estimated Practical Development Under Present Conditions" are given the following figures for the three Pacific Coast states:

Washington	1,200,000 h.p.
Oregon	950,000 h.p.
California	1,100,000 h.p.

It has been impossible to secure an explanation of the basis of this estimate. A comparison of the figure for this state with that of Harris' based on hundred-and-fifty-dollars-per-horsepower development indicates that the estimate is very conservative, and was probably obtained after very unfavorable consideration of present market limitations.

OTHER SOURCES OF INFORMATION

It had been hoped that it would be possible to prepare a list of power sites in the State showing location, amount of power available, and probable cost of development. Tables showing stream sections and amounts of power for certain areas in the State are to be found in the valuable Washington Water Power Series of the Water Supply Papers of the United States Geological Survey, which were prepared in cooperation with the Washington Geological Survey. These cover but a small part of the State, however, and it was not possible for the writer to obtain the desired information from other sources.

SUMMARY OF ESTIMATES

To summarize, it may be stated that there are published estimates of the amount of potential power in the State of Washington from three different sources, all based on different assumptions. That by Jackson and Hoar, which considers only developments practical under present conditions, gives the potential power as 1,200,000 horsepower, or over three times as much as the present developed power. That by Harris, assuming the development of all projects costing one hundred and fifty dollars per horsepower or less, gives the total potential power as 2,556,000 horsepower, or about eight times the present developed power. That by the Commissioner of Corporations, which contemplates the ultimate utilization of all power possible without regard to cost of development or location, and with a turbine efficiency of 75 per cent, gives the total potential power as 4,932,000 horsepower or fourteen and one-half times the present developed power. The different estimates cannot be compared on account of the difference in the assumed conditions, and the only generalization that can be made is that the amount of water power capable of development in the State of Washington, calculated on whatever basis it may be, is of such size as to be one of the large and important resources of the State.

COLUMBIA RIVER POWER PROJECT

INVESTIGATION BY FEDERAL AND STATE ENGINEERS

The development of water power at The Dalles on the Columbia River is a project so remarkable as to call for separate discussion. The Columbia River is the boundary between the States of Washington and Oregon, and the power of the site could not be said to belong exclusively to either Washington or Oregon. On account of its situation not far from the city of Portland, Oregon, a great deal of interest has been taken in the project in Oregon, and it has been carefully studied by a corps of engineers working under a cooperative agreement between the State of Oregon and the Department of the Interior. The results of these investigations have been published,³ and to this report the reader is referred for details.

GENERAL DESCRIPTION OF PROJECT

In general, the project involves the control and utilization for the generation of power, of the entire flow of the Columbia River at the head of Five Mile Rapids, near Grand Dalles, Washington. The total power resulting from this development, available at the bus bars twenty-four hours in the day and 365 days in the year, is estimated to be 480,000 horsepower. The installation of an excess of generating machinery over that required at the minimum flow period would be necessary to maintain the primary power mentioned, on account of loss of head resulting from the rising of the level of the tail water in flood water periods. At stages of the river between low and flood water, it would be possible to generate power in excess of the primary power. This seasonal power is estimated to be about 120,000 horsepower available for eleven months per year, 100,000 horsepower additional available for ten months per year, and yet another 100,000 horsepower available for eight months per year. Thus for eight months the total power available, including the primary, would be 800,000 horsepower.

CAPITAL COST AND COST OF POWER

The cost of the project was estimated at \$50,000,000. This amounts to about \$104 per horsepower of continuous power, \$62.50 per horsepower for all power which would be available eight months during the year, and \$46.30 per horsepower of total generating capacity. (This estimate was made in 1914 and was, of course, based on pre-war costs.) The cost of generated power was estimated under several assumptions. Interest rates of 3, 4 and 6 per cent were used in turn, the latter rate being used in connection with the assumption of a 10 per cent discount for marketing the securities, and 1 per cent taxes. The

³ Columbia River Power Project near The Dalles, Oregon, by L. F. Harza, Project Engineer, with special chapters by other contributors. Published by Technical Publishing Co., San Francisco.

first two rates represent those which might be expected if the project were constructed by the government, whereas the latter figure would more nearly approach the conditions under which the project could be financed by a private corporation. These rates were used with each of two sets of assumed market conditions. The first was that the entire output could be sold when the generating station was ready to operate. The second was that only a tenth could be sold when the generating station was ready to operate and that the sales would uniformly increase thereafter until at the end of the tenth year, the entire output would be sold. In addition, sets of figures were calculated on the assumption that the seasonal power also was sold at prices which made the power available for eleven months cost 80 per cents, the power available for ten months, 60 per cent, and the power available eight months, 30 per cent of the cost of an equal amount of power available for twelve months. And lastly, estimates were made considering different load factors, varying from a peak demand, or readiness to serve, basis, representing a load factor of 100 per cent, to the 50 per cent load factor near which figures commercial plants doing a general business operate.

The tables are so instructive that they are included here. It is to be remembered that they are purely hypothetical costs, were calculated before the war, and that they were based on capital costs which were relatively low when compared with most constructed projects on the same basis of rating. They were, however, reasonably and conservatively estimated, and illustrate admirably the variations in the cost of power caused by the different factors mentioned.

EXPLANATION OF LOW POWER COSTS

"It will be seen from the following tables that a company such as the local distribution companies, serving a mixed load at a load factor of about 50 per cent, would need to pay a price for power of about \$30 to \$37 per horsepower year of average consumption, or 0.46 to 0.57 cents per kilowatt hour, if the proposed power project were constructed upon the usual basis of corporate finance. These prices are comparable with the cost of generation under the assumed conditions, and include nothing for transformation, transmission or distribution of power, which expenses, if the power is transmitted far, add very greatly to the ultimate cost to large consumers and constitute the major proportion of the cost of serving small consumers. The apparently low prices of power in the following tables thus result from the cases based upon public construction at low rates of interest, and upon the use of the power at a high load factor of 80 or 90 per cent as in the case of the chemical industries, the power being purchased and used in the immediate vicinity of the generating station and at generated voltage."

TABLE IV
ANNUAL COST OF POWER

Annual cost of primary power if entire load is sold when generating station is ready to operate.

(Report on the Columbia River Power Project near The Dalles, Ore., by L. F. Harza, Project Engineer, Department of the Interior, U. S. Reclamation Service in Cooperation with State of Oregon, p. 67.)

	Interest Rate	Only primary load of 480,000 h.p. sold		Entire load of 800,000 h.p. sold at relative prices previously stated	
		Dollars per h.p. year	Cents per kw. hour	Dollars per h.p. year	Cents per kw. hour
Priced based upon charge for peak demand or on readiness to serve basis.....	3%	9.02	.....	6.63	.....
	4%	10.34	.....	7.58	.....
	*6%	15.13	.....	11.02	.....
Equivalent charge for average demand at 50% load factor	3%	18.04	0.275	13.26	0.202
	4%	20.68	0.316	15.16	0.231
	*6%	30.26	0.462	22.04	0.337
Equivalent charge for average demand at 80% load factor. Electro-chemical service.....	3%	11.28	0.712	8.29	0.128
	4%	12.92	0.197	9.48	0.145
	*6%	18.90	0.289	13.80	0.211
Equivalent charge for average demand at 90% load factor. Electro-chemical service.....	3%	10.01	0.153	7.37	0.113
	4%	11.49	0.175	8.42	0.129
	*6%	16.81	0.257	12.25	0.187

* On discounted bonds.

TABLE V

ANNUAL COST OF POWER

Table showing annual cost of power if only one-tenth of the power is sold when the station is ready to operate and the sales thereafter increase uniformly until the entire load is sold at the end of the first ten years.

(*Report of the Columbia River Power Project near The Dalles, Ore., by L. F. Harza, Project Engineer, Dept. of the Interior, U. S. Reclamation Service in Cooperation with State of Oregon, p. 67.*)

	Interest Rate	Only primary load of 480,000 h.p. sold		Entire load of 800,000 h.p. sold at relative prices previously stated	
		Dollars per h.p. year	Cents per k.w. hour	Dollars per h.p. year	Cents per k.w. hour
Priced based upon charge for peak demand or on readiness to serve basis.....	3%	9.85	.....	7.25	.....
	4%	11.65	.....	8.55	.....
	*6%	18.75	.....	13.70	.....
Equivalent charge for average demand at 50% load factor	3%	19.70	0.301	14.50	0.222
	4%	23.30	0.356	17.10	0.261
	*6%	37.50	0.573	27.40	0.418
Equivalent charge for average demand at 80% load factor	3%	12.31	0.188	9.06	0.138
	4%	14.57	0.222	10.70	0.163
	*6%	23.42	0.358	17.12	0.261
Equivalent charge for average demand at 90% load factor	3%	10.95	0.167	8.05	0.123
	4%	12.95	0.198	9.50	0.145
	*6%	20.85	0.318	15.22	0.233

* On discounted bonds.

PLANT NOT PRACTICABLE AT PRESENT

The general conclusions of the engineers who made the investigation and also of a board appointed by the Secretary of the Interior to review these investigations were that from an engineering standpoint the project seemed practicable. They did not consider, however, that "the growth of the power demand under normal conditions would be sufficient to absorb the output of the proposed plant until after the lapse of an uncertain but considerable period of years." This will be better understood if it is noted at the time the report was made the total generating capacity in both the steam and hydraulic plants of the five large public service corporations serving the Puget Sound, Spokane, and Portland districts (i. e., the territory that would be tributary to a plant at The Dalles) was only 341,500 horsepower, and that the primary power of the proposed plant was over one and one-third times as much as the capacity of the plants mentioned. No ex-

pansion of demand from ordinary commercial sources being imminent which would double the existing market for power, attention was turned to other outlets. The possibilities of absorbing large quantities of electric power in electro-metallurgical and electro-chemical industries were studied, but the results were mainly negative. These two classes of industry showed a probable market in the near future for only 30,000 horsepower if the plant were built. An investigation of the market for power for pumping water for irrigation purposes also gave negative results. For these reasons the board of review concluded that the development of the project could not be economically justified at that time, and stated that for some years to come the normal growth in power demand could be met most economically by additions to existing plants now only partially developed, or by the development of small projects more nearly proportional to the power which would be likely to be required in the succeeding years.

THE COST OF POWER

IMPORTANCE OF ELECTROMETALLURGY

The cost of power is one of the most important factors which affect the feasibility of establishing electro-metallurgical and electro-chemical industries. It is not, however, the only factor, because other considerations, such as the demand and the price obtained for the product, the cost of freight to the market centers, and the location and costs of raw materials exercise influences which, if unfavorable, may more than counterbalance the advantage of cheap power. Conversely, if the conditions are otherwise favorable, power which is relatively expensive can be profitably employed. An instance of this is the ability of ferro-manganese plants using comparatively expensive power to operate profitably during the war period, when the price of ferro-manganese was high.

But in general cheap power is an essential to electro-metallurgical and electro-chemical industries, and this usually requires that the power shall be generated by hydro-electric power plants. It is not possible to give a specific answer to the general question, "At what price can power be obtained?" because the cost of development of hydro-electric generating plants is not a standard figure such as may be given for steam generating stations, but differs according to the topography of the power site, the variations in stream flow, and the requirements of the consumer of the power. In Table VI are given some approximate cost figures for power when used for electric furnaces or electro-chemical purposes, with a high load factor. It will be noticed that a considerable variation in cost is shown.

TABLE VI
COST OF ELECTRIC POWER FOR ELECTRIC FURNACES OR ELECTROMECHANICAL PURPOSES WITH A HIGH-LOAD FACTOR
(*Lyon, Keeney & Cullen, The Electric Furnace in Metallurgical Work, Bureau of Mines Bull., 77, p. 70.*)

Location of Plant	Power Company	Nature of power	Cost per kw. year	Product at present time
Braintree, England	Lake & Elliott Steel Foundry	Gas engine	\$110	Steel
Sheffield, England	Municipal System	Steam	87	Do
La Paz, Savoie, France	Electrometallurgical Co. of France	Hydroelectric	16	Aluminum, steel, carbide
Léval, Isère, France	Keller, Leloux & Co.	Do	13	Ferro alloy
Égine, Savoie, France	Girard Electrometallurgical Co.	Do	18	Ferro alloy, steel
Bonn, Germany	Municipal System	Steam	92	Steel
Rensselaer, Germany	Lindenberg Steel Co.	Do	87	Do
Völklingen, Germany	Roehling Iron and Steel Co.	Steam, gas	83	Do
Menaker, Norway	Menaker Electric Smelting Co.	Hydroelectric	8	Ferro-alloys
Norwegian Sulphur Co.	Do	Do	7	Nitrates
Norwegian Sulphur Co.	Do	Do	5	Do
Tyssedal, Norway	Tyssedal Power Co.	Do	10	Carbide, cyanamide
Trollhattan, Sweden	Royal Powder Plant	Do	9 16 12	Iron, zinc, Ferro-alloy, paper
South Verdon, Vt.	Connecticut River Power Co.	Water and steam	53	General
Shelburne Falls, Mass.	Do	Water (secondary)	29	Do
Turners Falls, Mass.	Do	Water and steam	60	Do
Turners Falls, Mass.	Do	Water (secondary)	26	Do
Rumford Falls, Me.	Rumford Falls Power Co.	Hydroelectric	26	Paper
Niagara Falls, U. S.	Do	Hydroelectric	26	Electro-chemical
Niagara Falls, Canada	Do	Do	20	Do
South Carolina	Southern Power Co.	Do	25	Nitrates
South Chicago, Ill.	Illinois Steel Co.	Steam, gas	43	Steel
South Carolina	Southern Aluminum Co.	Hydroelectric	25	Aluminum
Snake River, Idaho	Southern Idaho Power Co.	Do	12	General
Hercules, Cal.	Northern California Power Co.	Do	16	Pig iron

CONDITIONS CONTROLLING COST OF DEVELOPING WATER POWER SITES

The topography of the power site determines whether reservoirs can or cannot be created, and whether dams, flumes, tunnels, canals, or pipe-lines are cheap or expensive. For instance, in one case there might be required an expensive dam, but no flume, tunnels, or canals, as in the case of a low-head plant utilizing the entire flow of a stream of considerable volume. In another case, there might be required a simple dam but an expensive flume or tunnel and penstock. Such a combination is to be found in many high head plants. Other cases require types of development totally different from either of these, and it is evidently necessary to consider any particular power site as an individual problem.

Influence of Variation of Flow.—The variation of the flow of the stream developed has an important bearing on the cost of power. If, for example, a plant is constructed which will utilize only a flow equivalent to that at the minimum flow period, during other periods of the year power is not utilized. In general, the additional cost of constructing a plant to utilize part of this surplus power over the cost of a plant for minimum flow only is by no means proportional to the increase of capacity, but is much less. Therefore the cost per horsepower of generating capacity when the plant is designed to utilize minimum flow only, is more than if the plant were designed to utilize part of the surplus (or as it is technically termed, secondary) power. In almost all hydro-electric plants constructed at the present time the installed generating capacity is greater than the capacity required at minimum flow, or if not, provision is made for ultimately installing such surplus capacity. If power up to the full generating capacity is required at all times, thus surplus power must be supplied from other sources during the low water period and is generally furnished by stand-by steam plants, which can be constructed more cheaply, per unit of capacity, than can hydraulic plants. The total cost of operating such a system is, however, the sum of the costs of operation of both the hydraulic and the steam plant, and wherever a steam auxiliary is included in a system, even though it operates little or none of the time, its cost of operation must be included in the calculation of the cost of power generated.

Storage.—The foregoing holds true whether storage is provided or not, if the term "minimum flow" is not limited to the natural minimum flow of the stream but includes the minimum flow as controlled by the dam and reservoir if storage is provided. The excess of the generating capacity which it is advantageous to provide over that corresponding to the minimum flow is, however, much reduced if the stream flow is partially equalized by storage. The ideal situation, from the viewpoint of continuous operation, would be that of a development with a reservoir of such capacity that all of the flood water would be caught and stored to be utilized at a later low water period, with the result

that continuous power could be generated equivalent to that furnished by a stream having a constant flow equal to the average flow of the stream. In such a case no auxiliary plant would be necessary. The cost of building such a reservoir, if it is a possibility, is often very great. Aside from the cost, it is often impossible to create a reservoir on account of the topography of the site. These factors prevent the attainment of the ideal. It is, however, approached more or less in many cases. Where a reservoir is part of a development the continuous power is a greater fraction of the total potential power of the stream flow than if the storage were not available. The auxiliary steam capacity necessary to insure continuous delivery of power equivalent to that produced by the total installed capacity of the hydraulic plant, then becomes a smaller part of the total installed capacity of the system, and the ratio of the cost of generating steam power to the total generating cost is correspondingly less.

Combination of Plants.—The transformation of secondary into primary power may be effected in another way. It often happens that the periods of minimum flow for two streams do not occur at the same time, and if plants on these two streams are part of a common system the surplus power of one plant may be used to supply the deficiency of the other at its low water period. The result is that each plant operates more nearly, or for a longer period, at its maximum capacity, than if they were not connected. This reduces the cost of power by increasing the amount of power that can be developed by the same given plant equipment, or to put it in other words, the interest and other charges are spread over a greater amount of power developed.

Load Factor.—The load factor has an important bearing on the cost of generated energy. It is evident that if a water power plant has a high load factor, the cost per unit of generated energy will be less than if the load factor were low, for the total cost of operating the plant is practically constant, regardless of the amount of power developed by the plant. This is illustrated by the figures in Table IV. Thus under one set of assumed conditions for financing, the cost per horsepower-year would be \$16.81 if the load factor were 90 per cent, but if it were 50 per cent, the cost would be \$30.26. Fortunately, the load factor for electro-metallurgical and electro-chemical industries is very high compared with that usually encountered by central stations; 90 per cent is a figure obtained by certain of these industries (although load factors in the eighties are more common) whereas a load factor of 40 per cent is common for ordinary central station loads.⁴

COST OF DEVELOPMENT

From the foregoing it will be seen that it is impossible to make any definite general statement as to the cost of power that may be

⁴ Dow, Alex. Trans. Am. Electrochem. Soc., vol. 32 (1917), p. 357.

generated in hydro-electric plants yet to be constructed. The sites that have been utilized heretofore have been those most easily developed and for this reason there has been a certain agreement of cost. The costs of these plants are doubtless less than those of plants to be constructed in the future, however, and the diversity of types of development makes generalization dangerous. It is probable that the cost of existing plants, not including very small ones, would have averaged \$100 if the plants which have in headworks and dams for greater capacities than are now installed in the power houses, had been completed, and that the developments in the future will cost more nearly an average of \$120 per horsepower of installed capacity, assuming that the design and size of the plants are such as would be dictated by good engineering and business judgment.⁵

RELATIVE COST OF PLANTS HAVING LARGE PROPORTION OF SECONDARY POWER

There are many power sites in this state where the variation in the flow of the stream is great, but where a power plant, which would deliver only a small amount of primary power, but a relatively large amount of secondary power, could be built at a cost per unit of installed capacity much less than of one in which the ratio of primary to secondary would be the customary ratio. The total amount of the fixed charges might, in such a plant, be sufficiently reduced as to more than counterbalance the decreased amount of energy generated yearly on account of the small minimum flow, and the cost of energy per unit might be less than that in a plant built according to customary practice.

Consider, for example, a plant which could be built at a cost of only \$60 per horsepower of installed capacity, and assume that it could operate at full capacity for eight months out of the year, but only at an average of 5 per cent of full capacity during the other four months. Consider also a plant costing \$120 per horsepower, but capable of operating nine months of the year at full capacity, two months at 50 per cent, and one month at 25 per cent of full capacity. The cost of energy generated in the first plant bears the relation to the cost of energy generated in the second of

$$\begin{array}{ccc} 60.00 & & 120.00 \\ 8 \times 1.0 + 4 \times 0.05 & \text{to} & 9 \times 1.0 + 2 \times 0.5 + 1 \times 0.25 \\ & & \text{or as five is to eight.} \end{array}$$

That is, the cost per unit of energy in the plant designed for large secondary power would be only five-eighths of that in the plant designed as usual. There may be cases in which cheap second-

⁵ The "Report of the Chief Engineer of the Public Service Commission of Washington on the Appraisal of the Washington Power Co." and those on some of the other appraisals made by the Commission contain interesting information as to the cost of construction of certain water power plants in the state, and may be consulted at the office of the Commission by those interested in detailed costs of these plants. Interesting data on the cost of hydro-electric plants are contained in Gillette and Dana's "Mechanical and Electrical Cost Data." The statement made here is the result of careful study of all the information available, either published or obtained by inquiry among well informed engineers.

ary power can be used, and there is undoubtedly a large difference in cost between primary and secondary to serve as an inducement to utilize secondary power. If secondary power be used, by an electro-metallurgical plant, interest charges on the increased size of plant required to produce the same yearly amount of product, and on the money tied up in the surplus stock required to maintain a constant output, have to be balanced against the saving in energy cost. A large proportion of primary power is generally found to be necessary for electro-chemical and electro-metallurgical industries.

COST OF POWER UNDER CERTAIN ASSUMED CONDITIONS

It will be interesting to take the figure of \$120 per horsepower as a basis, make some further assumptions, and estimate roughly the cost of generating power under assumed conditions. Let the size of a plant be 10,000 horsepower of installed capacity. The actual cost of operation and maintenance of each of two hydro-electric plants situated in this state and having a capacity somewhat near that specified, was approximately \$22,000 per year. If fixed charges for interest, taxes, insurance, and depreciation be taken at 10 per cent the cost of generation may be estimated as follows:

Fixed charges 10% on \$1,200,000.....	\$120,000
Operation and maintenance.....	22,000
Total cost per year.....	\$142,000
Total cost per horsepower of installed capacity per year..	\$14.20

This figure does not represent the cost of a particular amount of energy delivered, for the reason that the cost given is the same whether the plant operates at full capacity or only a fraction thereof. If for example the plant utilizes only a flow equivalent to the minimum flow (the minimum flow may have been increased by the use of storage) the power is all primary and the plant may run continuously throughout the year, in which case if the load factor were 90 per cent the cost of a horsepower-year would be \$15.80. If however on account of the fact that the installed capacity is such that there is not sufficient water to operate at full capacity during the minimum flow period, but is able to generate only 90 per cent of the continuous power that it could if it were able to operate at full capacity throughout the year, the cost, considering continuous power only, would be \$17.55 per horsepower-year. If possible to generate only 80 per cent the cost per horsepower-year would be \$19.70.

If the balance of the energy necessary to maintain at all times the full capacity of the plant were generated in a steam standby plant of 3,500 horsepower capacity, (this ratio of steam capacity to hydraulic is not uncommon on this coast) the total cost of owning and operating the two plants, if the steam plant generate 10 per cent of the total energy, might be as follows:

HYDRAULIC PLANT

Capital cost, 10,000 horsepower at \$120.00 per horsepower, or \$1,200,000.	
Taxes, insurance, depreciation, and interest, 10% of \$1,200,000.....	\$120,000
Operation and maintenance.....	22,000

STEAM PLANT

Capital cost, 3,500 horsepower at \$55.00 per horsepower, or \$192,500.	
Taxes, insurance, depreciation, and interest 12% of \$192,500.....	23,100
Operation and maintenance.....	16,000
Fuel oil, 7,884,000 horsepower-hours at 200 horsepower-hours per barrel, 39,420 barrels at \$1.00 per barrel.....	39,420
Total cost of 9,000 horsepower-years.....	\$220,520
Cost per horsepower-year.....	\$24.50

The figures for operation and maintenance, for the cost of fuel oil, and for the plants themselves, are all based on pre-war conditions. It is probable that prices will never return to those levels, but it is unquestionably true that the present high prices will not continue indefinitely, and for this reason, former prices have been used. It must be emphasized that this estimate is given merely for the purpose of illustrating, in a very general way, how the various elements enter into the cost of generating power under certain assumed conditions. These conditions are ones which might very probably be encountered in generating power for electro-metallurgical enterprises, but in any particular case, the conditions would be more or less different, and the cost given must not be taken as an answer to the question "At what price can power be obtained for electro-chemical industries?"

POSSIBLE ECONOMIES

Cost of transmission is not included in the preceding table. It is evident that the most advantageous situation for an electro-metallurgical or electro-chemical plant, as regards the cost of power, is at or near the generating station. In such a case, if the generating station were erected solely to supply power to the plant in question, transformers might be eliminated, either at both the generating station and the plant or at the generating station alone. The transmission line expense would also be small. Direct current generators might be used in the case of industries requiring direct current, and thus eliminate the machinery otherwise required for the transformation from alternating current. If, on account of the necessity of having good transportation facilities, or of having a good labor supply it is necessary to locate the plant at some distance from the generating station, standard transmission practice would have to be followed, involving step-ups transformers at the generating station, and step-down transformers, and rotary converters or motor-generator sets in the cases requiring direct current, at the plant.

SUMMARY

The foregoing discussion indicates the difficulty of making specific statements regarding the amount and cost of power to be developed from the streams of the state. It can only be said that there is a large

amount of potential water power in the state, that judging by past installations designed for central station service the costs of development and of the continuous power resulting will be relatively low compared with those in other parts of the United States, but that the extremely low costs of development and power of some of the Norwegian plants will not be reached. Costs of power and the proportions that these costs bear to the total costs of production of electrochemical products are such, however, that if Pacific and Oriental markets justify manufacture of these products, the water powers of the state can well supply the energy required.

PRESENT STATUS OF ELECTROMETALLURGY AND ELECTROCHEMISTRY IN WASHINGTON

Plants are engaged in the operation of four electro-metallurgical processes, and one electro-chemical process within the state of Washington. These are, the electrolytic refining of copper, the production of ferromanganese, the melting and refining of steel for foundry purposes in the electric furnace, the direct production in the electric furnace of steel from iron ore, and the fixation of nitrogen from the air by the arc process. Table VII gives data concerning the various plants in the state.

ELECTRIC STEEL MELTING FURNACES

General Remarks.—There are nine electric steel furnaces in operation in steel foundries in the state. They are all comparatively small; the largest is the six-ton Greaves-Etchells furnace installed at the Bremerton Navy Yard. Two companies have two furnaces each, but the remaining five are all in separate establishments. With one exception all the furnaces are acid-lined, and, of course, do no refining, the operations consisting simply of melting steel scrap. Four different types are used: The Girod, the Greene, the Rennerfelt, and the Greaves-Etchells.

The features common to all are a shallow hearth, side walls, and an arch, of suitable refractory materials, the whole inclosed in a boiler plate shell and so mounted on trunnions, rollers or rails as to be capable of being tipped. One or more electrodes enter the furnace through the roof. They are held in position by external supports fastened to the shell. A suitable tapping spout and door and also one or more charging doors are provided.

Girod Furnaces of Washington Iron Works Company.—The Girod type furnaces are installed at the plant of the Washington Iron Works; the larger one, a three-ton furnace, was installed by the Girod Company; the smaller one, which has a capacity of one ton, by the Washington Iron Works. It is exactly similar to the larger one in principle and proportion.

TABLE VII
ELECTROMETALLURGICAL AND ELECTROCHEMICAL INSTALLATIONS IN THE STATE OF WASHINGTON

NAME OF COMPANY	Location of Plant	Nature of Process	Equipment	Installed Capacity
Washington Iron Works.....	Seattle.....	Steel melting and refining for castings.....	1 3-ton, basic-lined, single-phase, Giroud steel furnace.....	800 kva.
		Steel melting for castings.....	1 1-ton, acid-lined, single-phase, Giroud steel furnace (made at the plant).....	800 kva.
Olympia Steel Works.....	Seattle.....	Steel melting for castings.....	1 2½-ton, acid-lined, two-phase, Greene steel furnace.....	700 kva. (2,400 kva. transformers, Scott connected)
Aurora Foundry Co.....	Seattle.....	Steel melting for castings.....	1 ¾-ton, acid-lined, single-phase, Greene steel furnace.....	300 kva.
Pacific Car and Foundry Co.....	Renton.....	Steel melting for castings.....	1 1½-ton, acid-lined, single-phase, Greene steel furnace.....	800 kva.
		Steel melting for castings.....	1 1½-ton, acid-lined, two-phase, Greene steel furnace.....	440 kva. (2,250 kva. transformers, Scott connected)
Skagit Steel and Iron Co.....	Sedro-Woolley.....	Steel melting for castings.....	1 ¾-ton, acid-lined, two-phase, Rennerfelt steel furnace.....	350 kva. (4,100 kva. transformers, Scott connected)
Puget Sound Navy Yard.....	Bremerton.....	Steel melting for castings.....	1 6-ton, Greaves-Etchells steel furnace.....	1,200 kva.
Everett Steel Co.....	Everett.....	Steel melting for castings.....	1 ¾-ton, acid-lined, two-phase, Greene steel furnace.....	300 kva.
Capitol City Iron Works.....	Olympia.....	Steel melting for castings..... (Not yet in operation)	1 1½-ton, acid-lined, two-phase, Greene steel furnace.....	440 kva. (2,250 kva. transformers, Scott connected)
Lamb Machine Co.....	Hoquiam.....	Steel melting for castings..... (Being installed)	1 1½-ton, acid-lined, three-phase, Greene steel furnace.....	500 kva.
Robert Process Steel Co.....	Seattle (Georgetown)	Production of tool steel from ore.....	Special three-phase furnace, similar to Greaves-Etchells steel furnace.....	525 kva.
Elilrowe Alloys Co.....	Tacoma.....	Ferromanganese production.....	6 2-ton, open top, Giroud ore furnace type furnaces. Hearth graphite carbon and tar mixture; magnesite side; fire brick top.....	2280 kva.
Seattle Smelting Co.....	Seattle (Van Asselt)	Ferromanganese production..... (Not now in operation)	1 2-ton, circular, open top, three-phase furnace. Conducting bottom is one electrode, two others are suspended from above.....	450 kva.
Tacoma Smelting Co.....	Tacoma.....	Electrolytic copper refining.....	3 Standard, multiple cell tank houses. Capacity, 204 million pounds of copper per year.....	3000 kw. *
American Nitrogen Products Co.....	La Grande.....	Production of sodium-nitrite by fixation of nitrogen of the air.....	Wielgoski furnaces.....	3000 kw. †

The three-ton furnace is lined with a mixture of California and Washington magnesite, with a silica brick arch. It is the only furnace in the state in which refining is done. A single electrode enters the furnace through a water-cooled ring in the arch. The other connection is made from a water-cooled plate at the bottom of the furnace by means of steel rods through the magnesite hearth; the latter arrangement is the distinguishing feature of the Girod furnace. The electrode is screwed onto a bronze, water-cooled, electrode holder, which is fastened to a cross piece which moves up and down between two upright guides fastened to the sides of the shell. The position of the electrode is controlled by an automatic regulator. The furnace is tipped by means of a hydraulic device.

The small furnace is acid-lined and the electrode is hand-regulated. The electrode holder grips the electrode from the side and permits the use of threaded connections. In this way the electrode is all utilized; there are no butt ends wasted as with the larger furnace. Amorphous carbon electrodes are used in both furnaces and are said to give better satisfaction than graphite ones.

Greene Furnaces.—The Greene furnaces were designed and installed by Mr. A. E. Greene, an engineer resident in Seattle. The shape of all the Greene furnaces (with the exception of the three-quarter-ton furnace at the Olympic Steel Works, and the furnace at the Pacific Car and Foundry Company's plant, which are more nearly of the proportions of the Girod type furnaces), is that of a cylinder with a horizontal axis with spherical segments at the ends. One or more carbon or graphite electrodes enter the furnace at the top through water-cooled rings, and a bottom electrode, consisting of a water-cooled steel plug, extends through the hearth from the shell to the bath. The furnaces are tipped for pouring by rolling the shell on rails by means of an hydraulic device. The single-phase furnaces have a single upper electrode and the hearth electrode. The two-phase furnaces have two upper electrodes connected to the phase busses of a two-phase, three-wire system, and the hearth electrode to the common bus. The electrode regulation is by hand, as in all furnaces in the state, with the exception of the large Girod at the Washington Iron Works and probably of the Greaves-Etchells at the Bremerton Navy Yard. The Greene furnaces are all acid lined.

Rennerfelt Furnace of Skagit Steel and Iron Company.—A three-quarter ton Rennerfelt furnace is installed at the plant of the Skagit Steel and Iron Company at Sedro Woolley. The peculiar feature of this furnace is the use of three electrodes, two of which enter the furnace from the sides at a small angle from the horizontal, whereas the third is vertical. The two side electrodes are connected to two legs of a two-phase power supply and the vertical one to the neutral. An interesting feature of this furnace is the use of corborundum bricks for the roof.

Greaves-Etchells Furnace at Bremerton.—The Greaves-Etchells furnace at the Bremerton Navy Yard employs three-phase power. There are two upper electrodes and the hearth lining acts as the third electrode.

Influence of Power Cost on Operation of Electric Steel Furnaces.—The steel furnace installations in the state do not indicate any unusual conditions. The rate for power for such purposes quoted at the present time by the public service corporation serving Seattle is 1.5 cents per kilowatt-hour. There are, however, old contracts still in force at lower rates. One old schedule for twenty-hour, off-peak operation was at the rate of 0.5 cents per kilowatt-hour, and the schedule which superseded this provides for a minimum rate of 1.0 cents per kilowatt-hour if the load factor (ratio of average to maximum load) for the month did not fall below 43 per cent. These rates are comparatively high, the amount of power consumed is small and the furnaces are used merely as a convenient method of obtaining molten steel for casting. They were erected to supply a local demand which absorbs nearly all of their production. Similar furnaces could be operated equally or nearly as well in almost any other locality furnishing a market, and the successful operation of the furnaces here has not resulted from the availability of cheap power, but from the demand for the product and the availability of the scrap steel which is the raw material used.

ELECTROLYTIC COPPER REFINING

At the smelter of the Tacoma Smelting Company, just outside of Tacoma, there is a refinery for treating the copper produced there, consisting of three tank houses each equipped according to standard practice for multiple refining. The yearly capacity is reported as 204,000,000 pounds.⁶ The power required for this capacity, at eight pounds of copper per kilowatt-hour, which is a fair average figure, is a little less than 3,000 kilowatts.

It should be borne in mind that electrolytic copper refining is but a single step in the entire process of producing refined copper from its ores. Copper refineries are almost always owned or controlled by the copper smelting companies on whom they depend for their supply of unrefined copper, and it is found advantageous, in most cases, to locate them near the market for refined copper, which is New York. The refinery at Tacoma is a part of the Tacoma Smelter and is one of the few refineries situated at the smelter. The largest copper refining centers, however, are on the Atlantic seaboard. They use power generated from fuel, and inasmuch as the cost of this power is only 15 per cent of the total cost of the operation, there is no reason to believe that the availability of cheap power in this state will ever be sufficient cause, in the face of the additional marketing costs

⁶Engineering and Mining Journal, January 11, 1919, p. 47.

which would result, for the establishment of any more copper refineries in this state.

PRODUCTION OF STEEL FROM ORE

The Rothert Process Steel Company is engaged in the production of high-carbon steel from magnetite ore brought from British Columbia. This is accomplished by reduction of the ore with charcoal in a furnace greatly resembling a Greaves-Etchells steel furnace. The furnace has a shallow magnesite hearth and a silica brick roof. There are two vertical upper electrodes extending through the roof, and embedded in the hearth is an iron plate, which, when the hearth becomes heated, acts as the third electrode. The furnace has a holding capacity of two tons of steel. The transformer equipment consists of three 175 kva. transformers connected in delta to give a low tension voltage of 100 volts.

The details of the operations are kept secret, and little can be said except that, apparently, good, high-carbon steel is being made in small quantities (not over a ton a day when operating). The steel is poured into split cylindrical ingot molds, and the resulting ingots are forged under steam hammers into bars of convenient size for the uses intended, usually toolmaknig. The control of the carbon content is said to be accomplished easily, as well as of the other metalloids. The ore is said to be a very pure one, and doubtless the forging into bars results very favorably on the physical characteristics of the steel.

FERRO MANGANESE PLANTS

BILROWE ALLOYS COMPANY PLANT AT TACOMA

The only ferro-manganese plant in the state in operation at the present time is that of the Bilrowe Alloys Company at Tacoma. In this plant manganese ores from Philipsburg, Montana, are mixed with sufficient coke for reduction, limestone for fluxing, and a little metallic iron, and then smelted in six, single-phase, open top, shaft furnaces. Each furnace has a capacity of a little less than two tons per day when operating on the best ores.

Description of Furnaces.—Four of these furnaces are inclosed in shells of 3/16 inch boiler plate, seventy-seven inches in diameter, sixty-nine inches high, flanged at the top, with a six-inch strip of brass running from top to bottom to break the magnetic circuit. The shells are water-cooled by a water spray from a perforated pipe which encircles the shell near the top. The other two furnaces are of reinforced concrete, 7½ feet square on the outside with a circular central shaft seventy-nine inches in diameter. The lining of both kinds of furnaces is the same. At the bottom is a water-cooled, cast-iron grid which is embedded in and under the rammed-in mixture of ground up carbon, graphite, and coal tar which forms the bottom of the crucible. The side walls of the crucible are made of California magnesite and

extend up above the smelting zone. Above this, the lining is a hard burned fire brick which will best withstand the abrasive action of the charge and of the poking necessary to insure proper descent of the charge.

The two concrete furnaces each have a guide which extends up from the sides and across the top of the furnace to hold the electrode in the center of the shaft. The other furnaces lack this feature, and their electrodes are merely supported by steel cables from a car truck overhead. In all except one furnace, 16-inch, square, amorphous carbon electrodes are used; in that one 20-inch round ones of the same material are used. The electrodes have threaded recesses in each end and new lengths are joined to the electrode in place by means of a threaded plug screwing into both pieces. A paste of graphite and raw linseed oil is used between the surfaces to increase the conductivity of the joint. Putting on a new length requires only from ten to fifteen minutes with the concrete furnaces, but from one to two hours on the other furnaces.

The electrode holders are all in two parts, which clamp on the sides of the electrodes. They are water-cooled. The flexible water connection required is an asbestos-covered $\frac{1}{2}$ -inch steam hose. These holders have arms which extend out past the side of the furnace where the clamps which make connections with the leads are bolted on. A counter weight balances this eccentric weight. Some trouble has been experienced with the holders, as the electrode faces are irregular and good contacts are not made over the entire surface. This results in hot spots, which eat away the carbon, sometimes producing an arc which attacks the copper, and, in some cases, allows the electrode to drop out.

Power Required.—The power required for each furnace is approximately 350 kilowatts. The current is supplied to the terminals of the furnace at about 55 volts. The power factor is said to be about 90 per cent. The conductors to the furnace, which are $\frac{1}{4}$ by 6-inch bars, are placed close to each other to minimize reactions, and the magnetic circuit in the shell is opened by the strip of brass mentioned before. The energy required per long ton of product is said to vary between 4,600 kilowatt-hours, which is the amount used when running on the best ores, to an average of 5,500 kilowatt-hours, which was the figure obtained over a period of four months while using the different grades of ore shown below. Power is purchased at rates varying with the load factor, and this is usually such as to earn a rate of from 3.31 to 3.52 mills per kilowatt-hour. Under the power contract, the plant is subject to shutdown in case of low water. During the past two years it has lost approximately ten days time with three or four partial interruptions.

Character of Ores.—The following analyses represent the different grades of Montana ore used:

	Mn %	SiO ₂ %	P %	Fe %	Al ₂ O ₃ %	Moisture %
Concentrates	49.13	9.4	.081	1.0	2.7	10.3
Washed ore	42.07	20.2	.092	1.3	4.0	12.2
Coarse good ore.....	47.98	15.08	.055	1.2	3.0	5.81
Coarse poor ore.....	38.27	23.4	.077	...	6.9	9.55

The concentrates are so fine that they tend to pack in the furnace so tightly that the gases formed by the furnace reactions cannot pass up freely. The result is that gas accumulates until the pressure is high enough to force a passage, which is usually along the electrodes, through which it "blows" with considerable force, materially shortening the life of the electrode. To minimize this trouble, coarse ore is mixed with the concentrate in equal quantities. It is also found necessary to so mix the ores that the Al₂O₃ content shall not exceed four per cent. Ores exceeding this amount are said to yield a slag which does not separate well from the metal, which is entangled in, and clings to, the slag when cool.

Character of Product.—Typical analyses of the ferromanganese and the slag produced are said to be as follows:

ANALYSIS OF FERROMANGANESE		ANALYSIS OF SLAG	
	%		%
Manganese	80.03	Manganese	13.97
Iron	11.5	Ferrous oxide.....	1.2
Silicon	0.6	Silica	34.7
Phosphorus	0.274	Lime	35.8
		Alumina	4.6

Details of Operation.—The ingredients of the charge are bedded in small bins and are mixed by shoveling into the charge cars which carry it to the furnace. The furnaces are fed continuously and are kept poked down at all times except within twenty minutes before tapping. It is desirable to have the furnace crust over before tapping so that no imperfectly separated material will be tapped out. The ferromanganese and slag are tapped into shallow cars every two hours, allowed to cool for several hours, after which slag and metal separate in a clean line if the charge has been correctly proportioned.

SEATTLE SMELTING COMPANY

The Seattle Smelting Company formerly operated a single ferromanganese furnace. This is a circular firebrick shaft eight feet in diameter, and eight feet high. Six 3 by 1 $\frac{1}{4}$ -inch iron bands bind the furnace together. The internal diameter is five and a half feet. The hearth bottom is made of a mixture of ground carbon and tar. Embedded under the hearth is a water-cooled iron plate which is attached to one of the three leads from the transformers. The other leads are connected by flexible copper strips to the cast iron electrode holders which grip two electrodes suspended vertically in the shaft of the furnace. Three phase power is supplied to the furnace at 55 volts by

transformer of 450 kva. capacity. The furnace produces about two tons per day when operating favorably. The power rate was based on a sliding scale involving the load factor; the minimum was one cent per kilowatt-hour.

The plant was avowedly erected to take advantage of the high prices of ferromanganese prevailing in the summer and fall of 1917. Its operations were hampered by lack of regular supply of electrodes, ore, and coke, and by the high cost of power, and did not attain consistent results. Data concerning them will therefore not be given. As a result of these difficulties, its small capacity, and the drop in the price of ferro-manganese, the operations of this plant were discontinued in May, 1918.

SODIUM NITRITE PRODUCTION

The operations of the American Nitrogen Products Company at Lagrande, are veiled in secrecy. The main facts are as follows: Furnaces of the Wielgolaski type oxidize the nitrogen of the air and the resulting gases are neutralized under proper conditions to form sodium nitrite. A little nitrate is unavoidably produced. Secondary power is purchased at the Lagrande power house of the Tacoma municipal system at the rate of \$10.00 per kilowatt year. This low rate is made to dispose of power otherwise wasted, and because of the disadvantage to the nitrite plant of the fact that it can obtain power only when there is a surplus over the other demands on the generating system. So far the plant has lost completely about three weeks in the fall and one week in the winter, and each day, except Sunday, it has to be run at half capacity for ten hours.

The operations have doubtless been very successful on account of the high price of sodium nitrite resulting from the great demand for this reagent in the new American dye industry. The company has the benefit of able technical advisers, and it seems probable that the company's activities will expand. At any rate it is notable as being the first large scale electrochemical industry established successfully in the State of Washington.

MARKET CONDITIONS

Steel from Electric Furnaces.—It is interesting to compare the market for the products of the plants discussed, and to note the influence of the cost of power. The castings produced by the foundries using electric steel furnaces are almost all for use in the immediate vicinity. Inasmuch as the rates paid for power in these furnaces are no lower than those which may be obtained in other cities, it is evident that the cost of power has had little influence in establishing furnaces in this locality.

Refined Copper.—The refined copper produced by the electrolytic refinery goes back to the eastern market, but the operations of a copper refinery, as explained before, are so intimately connected with

those of the copper smelter which supplies the unrefined copper, that if the refinery is not situated near New York (the market for refined copper) it will be situated at the smelter itself. The only reasons, therefore, for any more copper refineries being established in this state would be the establishment of another copper smelter in the state, or the creation of a primary market for refined copper here by reason of a demand from local factories or for export trade. In either case the cost of power would have little, if any, influence on its establishment.

Ferro-manganese.—The market for ferro-manganese, aside from a very small local demand, is in the east. During the war the urgent demand for ferro-manganese caused high prices which enabled the local plant to get well established. Future operations will be influenced by the following facts. High grade Brazilian manganese ore will become available in the east at lower prices as ocean shipping becomes more nearly normal. A similar drop in the cost of the domestic ores which the western plants have been using does not seem probable, as many of these mines could be worked to advantage only when the grade of ore specified was not as high as has been customary heretofore. A gradual drop in the selling price of ferro-manganese may be expected as part of a general decline in prices. It may be even more rapid, because during the war, on account of the scarcity of ocean transportation, the domestic production of ferro-manganese has been greatly expanded to compensate for the shrinkage of the imported supply, and the increased demand.⁷ When foreign competition again becomes a factor, it will further aid in depressing prices. Thus the item of freight to the eastern market will become a larger part of the cost of the alloy laid down in the east. Ferro-manganese production in Washington is, therefore, an industry in which the effect of the freight rates to the market, the availability of the raw material, and competition from other sources are factors as potent as the cost of power alone, and the future of the industry in this vicinity is problematical.

Sodium Nitrite.—The market for the sodium nitrite produced in the plant of the American Nitrogen Products Company is in the east, where the dyestuff industry is situated. During the war, on account of the high price obtained, transportation back to market had little effect on the success of the plant. Cheap power is an essential for this process, however, because the price for the product cannot be expected to remain at war-time levels, and although the question of a market for the product was thoroughly studied, there is no doubt that in this case the low cost of power was a large factor in the establishment of the plant here.

⁷ The domestic production in 1913 was 119,495 tons and the amount imported was 128,070 tons. The corresponding figures for 1918 are estimated to be 405,955 tons and 25,368 tons. See Iron Trade Review, LXIV, p. 118.

POSSIBILITY OF ESTABLISHING ELECTROMETALLURGICAL INDUSTRIES IN WASHINGTON

Among the electrometallurgical industries of general interest and application which are well established, either in this country or abroad, are those for the manufacture of aluminum, ferro-alloys, pig iron from ore, steel, and zinc by the electrolytic method. Electro-chemical processes for the manufacture of caustic soda and bleach, calcium carbide, corborundum and allied products, graphite, nitrogen compounds, and chlorides, are also well established. It has not been possible, in this paper, to present detailed studies of the possibilities of establishing these different industries in the State of Washington, but a general discussion of two of these will be given. The "Report on the Columbia River Power Project" mentioned heretofore contains two chapters dealing with the questions of establishing these industries at or near The Dalles; the first, by D. A. Lyon and R. M. Keeney on the "Feasibility of Western Electro-metallurgy" considers the industries first mentioned, and the second, by O. F. Stafford, entitled "Feasibility of Electro-chemical Industries at The Dalles" the other industries mentioned. Although these relate to the conditions at The Dalles, much of the data is equally applicable to other localities in the Pacific Northwest, and material will be freely abstracted from these sources.

ALUMINUM

Outline of Manufacture.—The process of the manufacture of aluminum requires two steps: the preparation of pure alumina, the oxide of aluminum, from the ore, bauxite, and the solution and electrolysis of this alumina in a bath of molten cryolite, resulting in the deposition of molten aluminum at the bottom of the bath. Bauxite, which is the naturally occurring hydrated oxide of aluminum, is never pure enough as mined to be used without purification. This is accomplished by calcining the ore, dissolving in caustic soda, precipitating alumina from this solution, and calcining the resulting precipitate. This purified alumina is then fed at intervals into a bath of used cryolite which is contained in a box-like furnace or pot the bottom of which acts as a cathode. The anodes are specially prepared amorphous carbon blocks suspended in the bath, and are gradually consumed by the oxygen liberated. The bath is kept molten by the heat generated by the passage of the current.

Raw Materials.—The raw materials required for the manufacture of aluminum are bauxite, coal and caustic soda for purifying it, cryolite and carbon in some form (usually as petroleum coke) for making electrodes. There are no bauxite deposits of large size known in Western United States. If domestic ore were to be used in a plant in Washington, it would be necessary to procure the ore from the eastern deposits, those in Arkansas being the nearest and also of the highest

grade. Large deposits of high grade bauxite were being opened up in British Guiana before the war, and a considerable amount of this material has been used at the Soller's Point plant of the Aluminum Company of America, in Maryland. Permits for developments beyond those then licensed were not granted by the British government during the war, and it is said that operations in the future are to be governed by the policy of conserving the mineral wealth of the British Empire for itself.⁸ If these deposits become available they might be a very attractive source of raw material for an aluminum plant on the Pacific Coast. Deposits of bauxite are also found in Dutch Guiana. India produces bauxite of high grade, and ore from that source might also be available for a Pacific Coast plant. These latter sources involve ocean transportation, however, and although this may be an advantage when the shipping industry becomes more nearly normal, it is thought best not to consider the use of these ores in this discussion. Cryolite is mined in Greenland, which furnishes the world's supply. It is possible to substitute an artificially made fluoride of aluminum and sodium; this is done to some extent by the European manufacturers. Coal and caustic soda for bauxite purification are readily available both in Arkansas or in this state; purification of the bauxite at the mine would, however, save freight. Petroleum coke is readily available from the California oil refineries; charcoal could also be readily obtained if a steady and reliable demand for it were assured.

Cost of Production.—Lyon and Keeney give the following estimate of the cost of producing aluminum at The Dalles:

COST OF PRODUCTION OF ALUMINUM PER SHORT TON AT THE DALLES

2 tons of alumina, \$28.75 per ton.....	\$ 57.50
200 pounds of cryolite, 1.5 cents per pound.....	3.00
1,400 pounds of electrodes, 5.0 cents per pound.....	70.00
Other fluxes, etc.....	10.00
28,000 kilowatt-hours, 0.2 cents per kilowatt hour.....	56.00
Labor (Average wage \$2.50 per day).....	70.00
Repairs	10.00
Amortization, depreciation, 5 per cent each.....	18.00
Interest, 6 per cent.....	10.00
General	20.00
Total	\$324.50
Cost per pound.....	\$0.1622

This estimate is based on the assumption of a plant requiring 25,000 horsepower or more, and of the use of alumina made from bauxite at or near the mine in Arkansas. The cost of power is based on a flat rate of \$10 per horsepower year at the generating station, a 90 per cent load factor and a loss of 15 per cent in line, transformers, and motor-generators. The addition of \$15 for freight to New York, and of \$20 for marketing expenses, brings up the cost to \$360 per ton in round numbers, or 18 cents per pound.⁹

⁸ Mineral Industry in 1917, p. 28.

⁹ These figures were based on before the war conditions. They are presented unmodified because of the difficulty of forecasting what changes in prices will permanently result from the war.

Disadvantages of Manufacture on the Pacific Coast.—Some of the disadvantages of producing aluminum on the Pacific Coast are brought out in this estimate. Freight for the eastern producer is only a small fraction of what this charge would be for a Pacific Coast producer; on alumina it would be \$18.50 and on the metal \$15.00 for the latter. The cost of labor used above is assumed to be two-thirds greater than if the plant were in the east; the increase would be \$28.00 per ton. These three items amount to three cents per pound or 17 per cent of the total.

The cost of power that was used as a basis is extremely low. The expected cost at The Dalles if the project were financed in the usual manner was estimated at \$15.13 per horsepower-year instead of \$10.00, the figure given to Lyon and Keeney on which to base their calculations, and which figure could only be attained if the plant were constructed by either the federal or state government. If more expensive power were used the cost of production would be correspondingly increased.

Market Conditions.—The production of aluminum in the United States in 1917 was estimated to be 200,000,000 pounds,¹⁰ which is nearly triple the production in 1913. The average yearly increase since 1913 in the annual production was about 34,000,000 pounds. The 1917 production may be taken as a measure of the capacity, for all plants were working at full capacity. It is stated that this capacity will be doubled by the completion of the plants of the Cheoah Aluminum Company, a subsidiary of the Aluminum Company of America, thus making the producing capacity roughly four million pounds a year. It is difficult to forecast future consumption, but it is evident that the present American producer is providing ample producing capacity to take care of a great expansion of demand, and that any new company entering the American market would have strong competition from a producer of great financial strength, whose cost of production is less than that of a western plant on account of the fact that the raw material and the market are both near the factory in the east.

The selling price of aluminum at New York was as low as 18 cents a pound in 1914 and almost as low in 1912. At such prices a plant operating at The Dalles with such costs as above would have just made expenses, whereas the eastern producer would still be able to make a profit. For these reasons the manufacture of aluminum does not seem attractive on the Pacific Coast at the present time. The Pacific Coast and the Oriental markets may, it is true, expand sufficiently to make a western plant advisable, but until that time it does not seem that there is sufficient reason to justify the erection of such a plant.

¹⁰ Mineral Industry during 1917, p. 13.

ELECTROCHEMICAL PRODUCTION OF ZINC

Possibility of Establishing a Plant in Washington.—The treatment of zinc ores by the electro-chemical method has been of importance only in the last few years, but is now a well established industry. During the year 1918 39,098 short tons of spelter were produced in the United States by this method.¹¹ The fact that the neighboring states of Idaho and Montana are large zinc ore producers makes it interesting to study the possibility of establishing an electrolytic zinc plant in the state of Washington.

Zinc Ore Resources of the Pacific Northwest.—The mine output of zinc in the state of Washington during 1917 was 1,195,567 pounds. At the present time practically all of the production is from the northeast corner of the state. This is a very small amount compared with the production in neighboring state, that in Idaho for the same year being 79,854,136 pounds¹² and in Montana, 186,259,331 pounds.¹² It is possible that if an electrolytic zinc plant were established in the state some of the many prospects might be developed into producers. This would result both on account of creating a local market for zinc ores, thus eliminating freight to eastern distilleries, and substituting freight on the much smaller weight of zinc produced, and also because ores can be treated in such a plant whose composition is such that they cannot be commercially treated at the present time by the retort method. This latter point will be discussed later. However the fact that after many years during which these regions have been available for prospecting and development and in which time no little money has been spent for exploitation, no important producing district of assured future has been developed, gives no great hope for large future development. It must be admitted that at the present time any zinc plant in Washington could not depend on local ores for its supply.

In Idaho the situation is quite different. The Coeur d'Alene district has been an important producer of lead-silver ores for many years, and a steady zinc producer during recent years, and the size and continuity of its ore deposits give assurance of its productivity in the future. Montana is a large and well established zinc producer, the Butte district being one of the most important in this country. Table XIII, gives the mine production of lead and zinc in the three states under discussion.

Ores Amenable to Treatment.—Sulphide ores or concentrates containing less than 40% zinc are not salable to retort plants. This has made impossible the utilization of raw ore or concentrate that contained less than that amount, while at lead smelteries, ores containing over about five per cent are penalized. This penalty makes unprofitable the smelting of ores containing over about 10 per cent zinc. Thus the field of zinc-lead ores, or concentrate therefrom, con-

¹¹ Engineering and Mining Journal, vol. 107, p. 57.

¹² Mineral Industry during 1917, p. 741 *et seq.*

TABLE VIII
MINE PRODUCTION OF ZINC AND LEAD IN IDAHO, MONTANA AND WASHINGTON
FROM "MINERAL RESOURCES"

YEAR	IDAHO		MONTANA		WASHINGTON	
	Zinc lbs.	Lead lbs.	Zinc lbs.	Lead lbs.	Zinc lbs.	Lead lbs.
1912	13,903,502	284,185,657	26,918,881	7,446,749	.....	127,387
1913	23,173,953	317,871,945	88,673,083	10,935,827	.....	202,487
1914	42,012,435	348,526,069	111,580,554	9,656,008	.....	65,507
1915	70,153,234	343,999,466	187,146,895	13,756,356	244,906	295,215
1916	86,505,234	375,081,781	229,233,075	13,595,136	1,693,734	.....
1917	80,000,000 approx.	383,000,000 approx.	180,000,000 approx.	17,000,000	1,000,000 approx.	9,000,000 approx.
YEAR						
	Zinc Value	Lead Value	Zinc Value	Lead Value	Zinc Value	Lead Value
1912	\$ 959,479	\$12,788,355	\$ 1,857,403	\$335,104	.....	\$ 5,732
1913	1,297,741	13,986,366	4,965,693	481,176	.....	8,909
1914	2,142,634	13,592,517	5,690,608	376,584	.....	2,555
1915	8,690,001	16,261,975	23,206,215	646,549	\$30,368	13,875
1916	.....	25,883,643	.....	.....	.....	.....
1917	7,336,000 approx.	34,595,000 approx.	.....	.....	.....	824,000 approx.

taining less than 40 per cent or over 15 per cent zinc is covered neither by the zinc distillery nor by the lead smelter. These ores, however, are amenable to treatment by the leaching-electrolytic method, and the statement is made by Mathewson¹³ that by reason of this development the complex problem "now is practically solved."

Description of Process.—The process at Great Falls, which is essentially that used elsewhere, is summarized by Mathewson as follows:

"First careful roasting of the concentrate at temperatures not exceeding about 730° C.; then dissolving the zinc together with a little iron by means of spent electrolyte in Pachuca tanks. A small amount of manganese dioxide is then added to effect the oxidation of the iron, which is then precipitated by means of powdered limestone, bring down any arsenic and antimony that may be dissolved. These are separated in Oliver filters and the residue sent to the blast furnaces, while the filtrate, which contains nothing but zinc with a little cadmium and copper, is then treated with zinc dust and again filtered, the filtrate being the pure solution which is sent to the tank rooms. The anodes are pure lead and the cathodes pure aluminum. The deposition goes on for 48 hours only, when the zinc is stripped from the cathode sheets, then melted into slabs."

The extraction obtainable varies widely, depending on the amount of iron present in the ore and the temperature during roasting. Hamilton Murray, and McIntosh¹⁴ have shown that the formation of the insoluble ferrate ZnOFe_2O_3 does not occur at 1100° F., 594° C., when working with pure zinc oxide and ferric oxide, but does at higher temperatures to an extent dependent upon the temperature and length of time of heating. On account of the formation of this compound extractions may be as low as 65 per cent, which was said to be the extraction at Trail in 1916,¹⁵ or that obtainable with certain Colorado ores high in iron,¹⁶ and on the other hand straight blende ores can be treated to give almost complete extraction. The extraction at Great Falls is said to vary between 85 per cent and 95 per cent.¹⁶

Power Requirements.—The total amount of power required in actual operation will vary between 3,000 to 4,000 k.w.h. per ton of zinc produced.¹⁷ This is the largest item in the cost of production. Just how much it is possible to pay for power depends on other factors, such as cost of labor, freight on ore to the plant and freight on the spelter to the markets. Hanson,¹⁸ in an estimate of the cost of treating

¹³ Mathewson, E. P., Electrodeposition of Zinc from Aqueous Solution, Bull. Canadian Min. Inst., March 1917, p. 241.

¹⁴ Hamilton, E. H., Murray, G., and McIntosh, D., Formation of Zinc Ferrate: Bull. Can. Min. Inst., July 1917.

¹⁵ Rickard, T. A., Electrolytic Refining at Trail, M. & S. P., vol. 113, no. 26, p. 903-7. (Dec. 23, 1916)

¹⁶ Ingalls, W. R., Electrolytic Zinc, E. & M. J., March 4, 1916.

¹⁷ Hansen, C. A., Electrolytic Zinc, Bull. A. I. M. E., Mar., 1918, p. 615.

¹⁸ Hansen, C. A., Hydrometallurgy of Zinc and Lead. Met. & Chem. Eng., vol. XIV, p. 121. (Feb. 1, 1916)

Butte & Superior Copper Company concentrate containing 55 per cent zinc, showed that with power at \$30 per horsepower-year, an electrolytic plant at Butte could advantageously compete in the St. Louis and New York markets with a retort plant in Oklahoma. Zinc ores with 25 per cent to 45 per cent zinc could carry somewhat higher rate so long as the retort process continued to fix the value of zinc ore or concentrate delivered to the electro-chemical plant."

Cost of Operation.—With Hanson's figures as a basis, calculations have been made showing the costs of treating zinc ores of the same kind as the Butte and Superior ore considered by him, assuming the same recovery, in the eastern part of Washington. It is also assumed that the ore is brought from Wallace, Idaho, to some point as far from Wallace as is Northport, where power is available at the various rates from which the costs are figured. This assumption was made in order that certain commodity rates which are in force from Northport could be applied. The rate from Wallace is assumed to be the same per ton mile as is the present rate on copper ores between Butte and Great Falls. The results indicate that, under the assumed conditions, it would be cheaper to treat zinc ores from the Couer d'Alenes in Washington in the wet way than by sending them to Kansas or Oklahoma distilleries, if power can be obtained for \$20 per horse-power-year or less without making allowance for differences in recovery. Taking these into account the advantage is increased. Tables IX., X. and XI) show Hansen's figures and those derived from them.

The cost of an electro-chemical plant at Butte, having a capacity of two hundred tons of zinc per day, completely equipped, but not including the cost of the primary power plant, was estimated by Hansen to be between twelve and thirteen thousand dollars per ton of daily capacity. The cost of an electro-chemical plant producing ten tons per day would be between twenty and thirty thousand dollars per ton of daily capacity. The corresponding cost for a complete retort plant, including roasters and pottery, of two hundred tons daily capacity would be from fourteen to sixteen thousand dollars per ton of daily capacity, depending on its location, and for a ten ton retort plant something near the figure for an electro-chemical plant of equal size.

The above comparison was for 55 per cent zinc ores. No such comparisons have been made for the lower grade ores. French¹⁹ gives figures showing costs for the production of zinc from 30 per cent ore containing also 15 per cent lead and 12 ounces silver per ton, in a plant having a capacity of twenty-five tons of zinc per day.¹⁹ His figures are higher than Hansen's, as would be expected with a smaller plant, and in different form, but they indicate that with the same cost of power as Hansen used, zinc at New York would cost three cents per pound, and that the lead and silver would be recoverable as well. In as much as such an ore would be unsalable to a retort plant and as

¹⁹ French, Thomas, Future of Electrolytic Zinc. Pittsburgh Meeting. Am. Electro-chem. Soc., Oct. 3, 1917.

this figure gives a good margin for mining the ore, and marketing expense, the result is very favorable.

It should be noted that both these estimates are based on before the war conditions, and should be modified in order to be used as a basis at present. It is thought best to leave them as they are rather than attempt to forecast post-bellum conditions. If the elements which enter into the cost of production remain high in price, undoubtedly the price of spelter will also maintain a high level, and in that instance electrolytic zinc production should be very attractive in Washington.

TABLE IX

COMPARATIVE COST PER TON ZINC FOR TREATING BUTTE AND SUPERIOR ORE
AS GIVEN BY C. A. HANSEN

	Retort process Oklahoma		Electrochemical process, Butte, Montana	
Plant capacity tons zinc per day.....	200		200	
Cost per ton zinc:				
Salaries	\$ 1.25		\$ 0.93	
Labor at \$1.75, \$2.00 and \$3.50.....	11.30		6.00	
Gas at 4c	2.93		....	
Coal at \$2.00	1.67		....	
Power at \$26.00 per h.p. yr. 3680 kw. hr....	....		14.65	
Clay	0.63		....	
Repairs and sundries	1.04		4.14	
Fixed capital charges 16½% first cost....	\$18.82		\$25.72	
	6.36		5.70	
Total treatment cost	\$25.18		\$31.42	
Freight on concentrate to Oklahoma.....	16.62		0.00	
	\$41.80	\$41.80	\$31.42	\$31.42
Freight to St. Louis on zinc.....	....	2.60	....	9.00
Freight to New York on zinc.....	7.20	....	10.00	....
Treatment cost and freight per ton zinc:				
f.o.b. St. Louis .....	....	\$44.40	....	\$40.42
f.o.b. New York	\$49.00	....	\$41.42	....
Above figures neglect mining and milling costs to produce concentrates; also neglect relative recoveries of zinc values which would be:				
For retort process, say.....	\$7.0%	....	....	....
For electro-chemical process .....	....	....	....	93.0%
Correcting for relative recoveries, the relative treatment and freight costs on above basis would be about:				
For St. Louis delivery .....	....	\$44.40	....	\$37.06
For New York delivery	\$49.00	....	\$38.06	....
Equivalent cost per lb. zinc.....	2.45c	2.22c	1.903c	1.853c
Net value of silver, lead, copper in residues from Butte-Superior concentrate (26 oz. Ag.)	\$7.20		\$22.70	

TABLE X

COST PER TON OF ZINC MADE IN ELECTROLYTIC PLANT IN WASHINGTON FROM
COEUR D'ALENE ORE

Assuming power costs as below and freight rates proportional to Butte-Great Falls rates.

	POWER RATES, DOLLARS PER HORSEPOWER-YEAR				Bartlesville Retort Plant
	\$10.	\$12.	\$15.	\$20.	
Salaries	\$0.93				
Labor	6.00				
Repairs	4.14				
Fixed capital charges	5.70				
Freight on 1.96 ton to Washington point at \$3.54	6.95				
Freight on spelter to New York at \$12.00 per ton.....	12.00				
Operating costs exclusive of power..	\$35.72	\$35.72	\$35.72	\$35.72	
Power	5.64	6.77	8.46	11.28	
Total cost per ton of zinc:					
f.o.b. New York.....	\$41.36	\$42.49	\$44.18	\$47.00	\$52.78
f.o.b. St. Louis	39.36	40.49	42.18	45.00	48.18

TABLE XI

COST PER TON OF ZINC MADE FROM COEUR D'ALENE ORE IN A RETORT PLANT
AT BARTLESVILLE, OKLAHOMA

Salaries	\$ 1.25			
Labor	11.30			
Gas at 4c per cu. ft.	2.93			
Coal at \$2.00.....	1.67			
Clay	0.63			
Repairs and sundries	1.04			
	<u>\$18.82</u>			
Fixed charges	6.36			
Total treatment charges	\$25.18	\$25.18	\$25.18	\$25.18
Freight, Okla., on conc. 2.09 ton at \$9.75.....		20.40	20.40	20.40
		<u>\$45.58</u>	<u>\$45.58</u>	<u>\$45.58</u>
Freight zinc to New York.....			7.20	
			<u>\$52.78</u>	
Total to New York.....				2.60
Freight zinc to St. Louis.....				<u>2.60</u>
Total to St. Louis.....				<u>\$48.18</u>
Correcting for recoveries, which are 87% for retort and 93% for electrolytic, deduct				
.06 × 52.78 = 3.41 from cost of electrolytic zinc for New York delivery and				
.93				
.06 × 48.18 = 3.11 for St. Louis delivery.				
.93				
POWER RATES, DOLLARS PER HORSEPOWER-YEAR				
	\$10.	\$12.	\$15.	\$20.
Cost per ton electrolytic zinc at New York.....	\$41.36	\$42.49	\$44.18	\$47.00
Deduct	3.41	3.41	3.41	3.41
Equivalent cost per ton electrolytic zinc at New York	<u>\$37.95</u>	<u>\$39.08</u>	<u>\$40.77</u>	<u>\$43.59</u>
Cost per ton retort zinc.....	\$52.78			
Cost per ton electrolytic zinc at St. Louis.....	\$39.36	\$40.49	\$42.18	\$43.59
Deduct	3.11	3.11	3.11	3.11
Equivalent cost per ton electrolytic zinc at St. Louis	<u>\$36.25</u>	<u>\$37.38</u>	<u>\$39.07</u>	<u>\$40.48</u>
Cost per ton retort zinc.....	\$48.18			

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The Engineering Experiment Station was formally organized in December, 1917, in order to coordinate the engineering investigations in progress and to facilitate the development of industrial research in the University.

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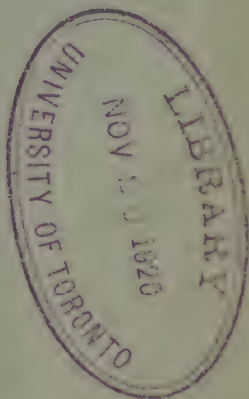
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UNIVERSITY OF WASHINGTON
ENGINEERING EXPERIMENT STATION

ENGINEERING EXPERIMENT STATION SERIES

BULLETIN No. 6

ORNAMENTAL CONCRETE
LAMP POSTS

BY
CARL EDWARD MAGNUSSON
Professor of Electrical Engineering



SEATTLE, WASHINGTON
PUBLISHED QUARTERLY BY THE UNIVERSITY
JULY, 1919

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ENGINEERING EXPERIMENT STATION

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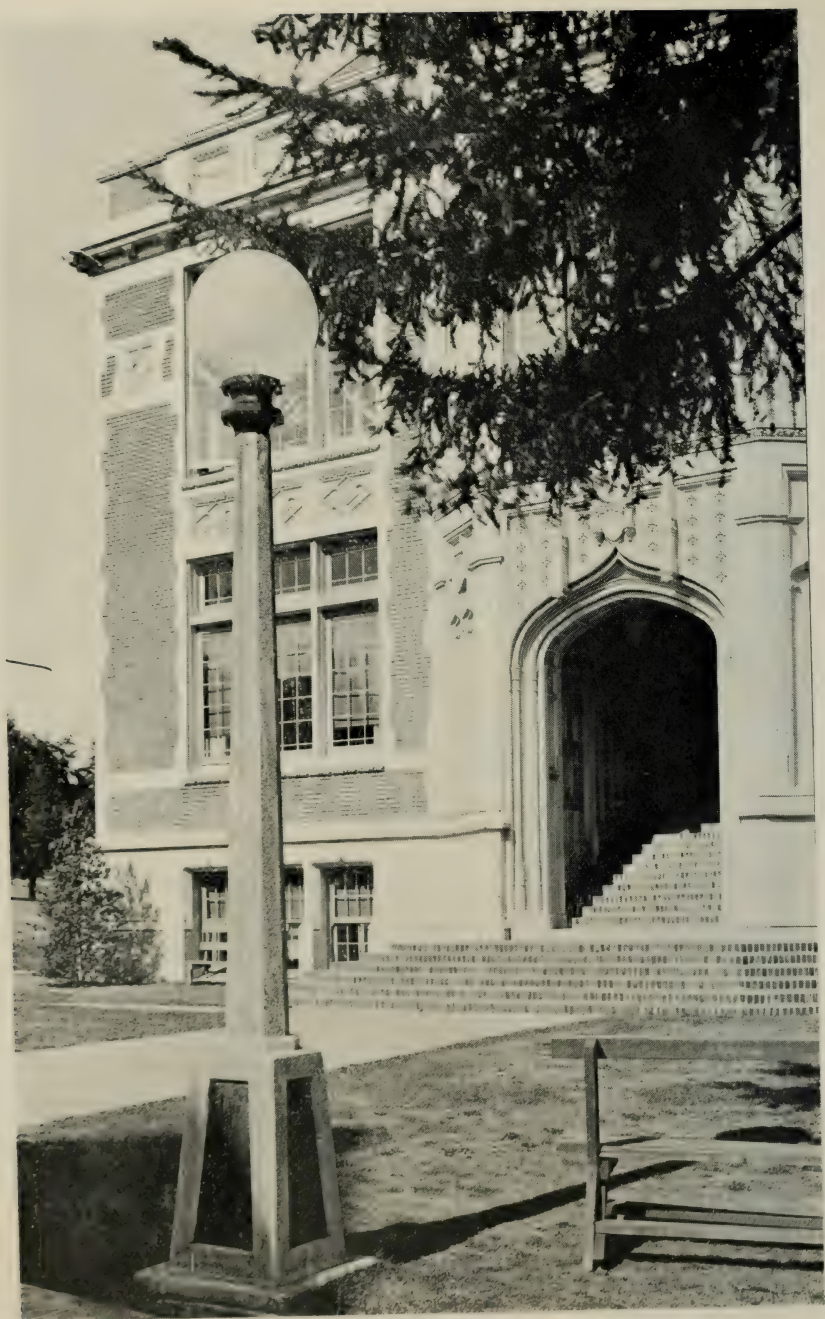


FIG. 1. WEST ENTRANCE, HOME ECONOMICS HALL
UNIVERSITY OF WASHINGTON

ORNAMENTAL CONCRETE LAMP POSTS

By C. EDWARD MAGNUSSON

Concrete lamp posts of the design shown in the accompanying photographs have given satisfactory service during the past eight years on the campus of the University of Washington.* Seventy poles were constructed and installed in 1911, and a second set of ninety poles of the same design were manufactured and placed in service in 1914.

The ornamental character of the poles need not be discussed, as the accompanying photographs of poles in position give ample evidence. Modifications in the color selected for the base panels and of the iron cap supporting the glass globe might be desirable.

While the structural material is chiefly concrete, the nature of the design requires the use of iron for certain parts. Thus a central iron pipe forms the core of the pole; an iron plate is used as a door on one side of the base; on top is an iron shade holder, which supports the glass globe; two iron plates in the base give the required strength to the pedestal, and four iron bolts are embedded in the concrete sub-base in order to firmly hold the post in position.

*The poles were designed and constructed by the late Mr. Frank E. Johnson, instructor in Electrical Engineering, who had charge of the campus lighting in 1905-15.

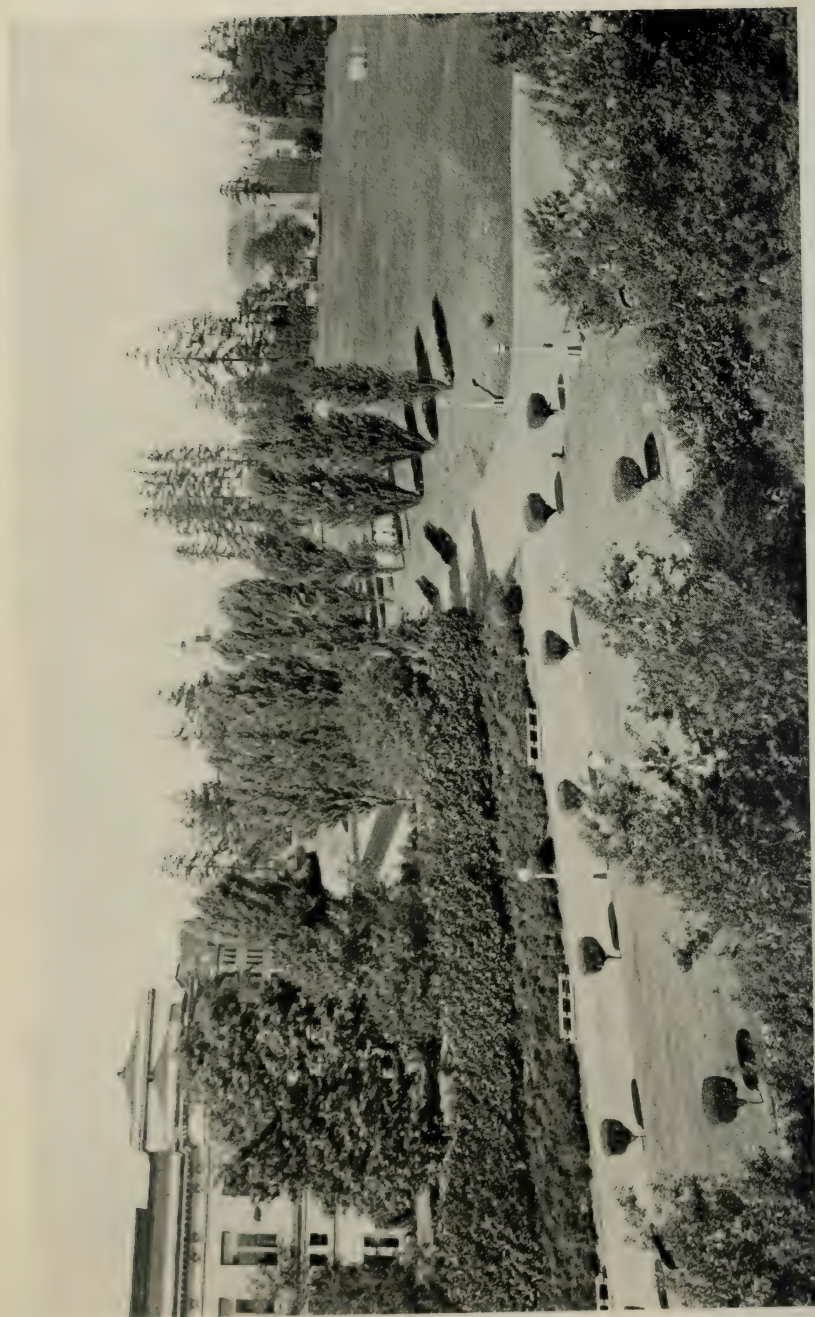


FIG. II. LOOKING NORTH FROM BAGLEY HALL
UNIVERSITY OF WASHINGTON

Gravel.—In preparing the concrete, considerable care was taken in the selection of the gravel aggregate. A preliminary series of experiments was made to determine what size of gravel would produce the best results. Six sample blocks are shown in Figure III, for which the gravel was in each case passed through a narrow range of screen mesh.

In the poles on the campus such sized gravel aggregate was used as will pass through a screen of three mesh to the inch and remain on a screen of six mesh to the inch. Selected roofing gravel was purchased and passed over two shaking screens bolted together and operated by a 5 h. p. motor. The top screen carried the coarse gravel to one side, the lower screen delivered the desired aggregate, and the sand and fine gravel were collected in a box underneath the two screens. No sand was used in the concrete mixture, as this has a tendency to give the surface a rough and dingy appearance. In Fig. IV is shown the surface of the finished concrete pole on a reduced scale.

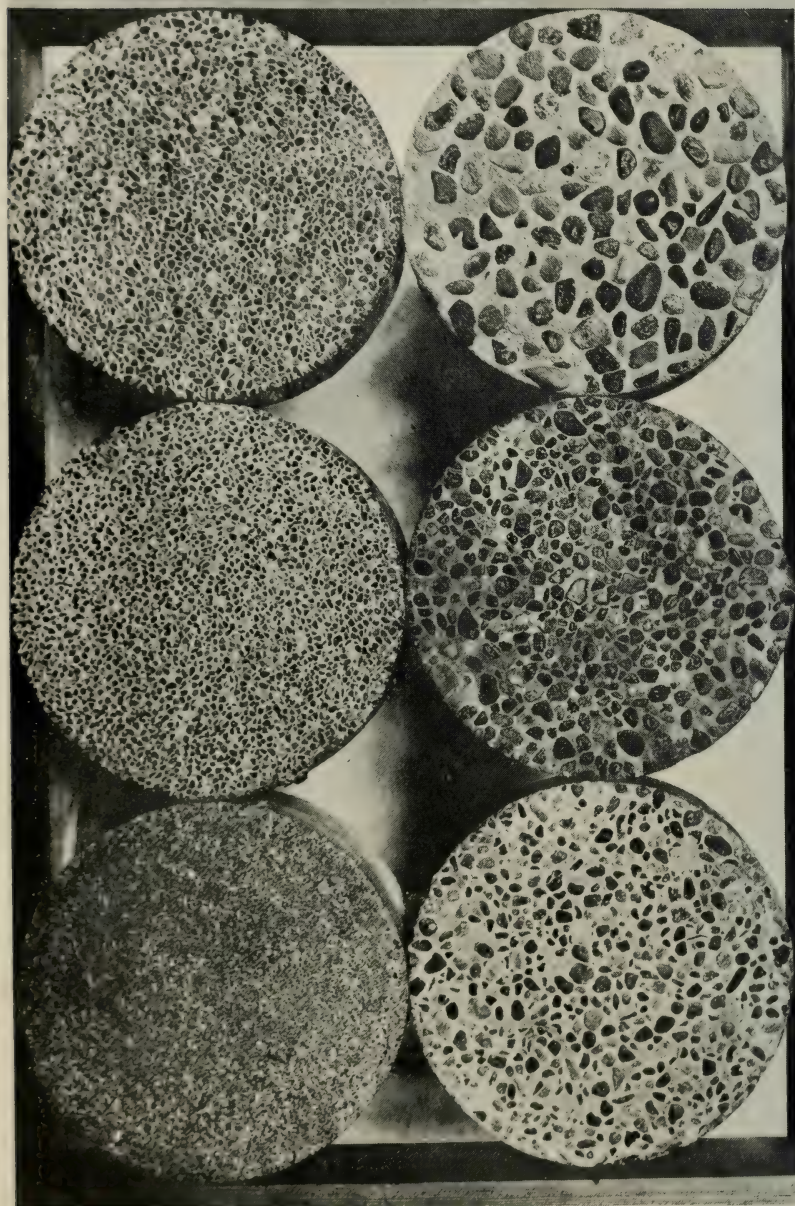


FIG. III. TEST BLOCKS, EACH EIGHT INCHES IN DIAMETER

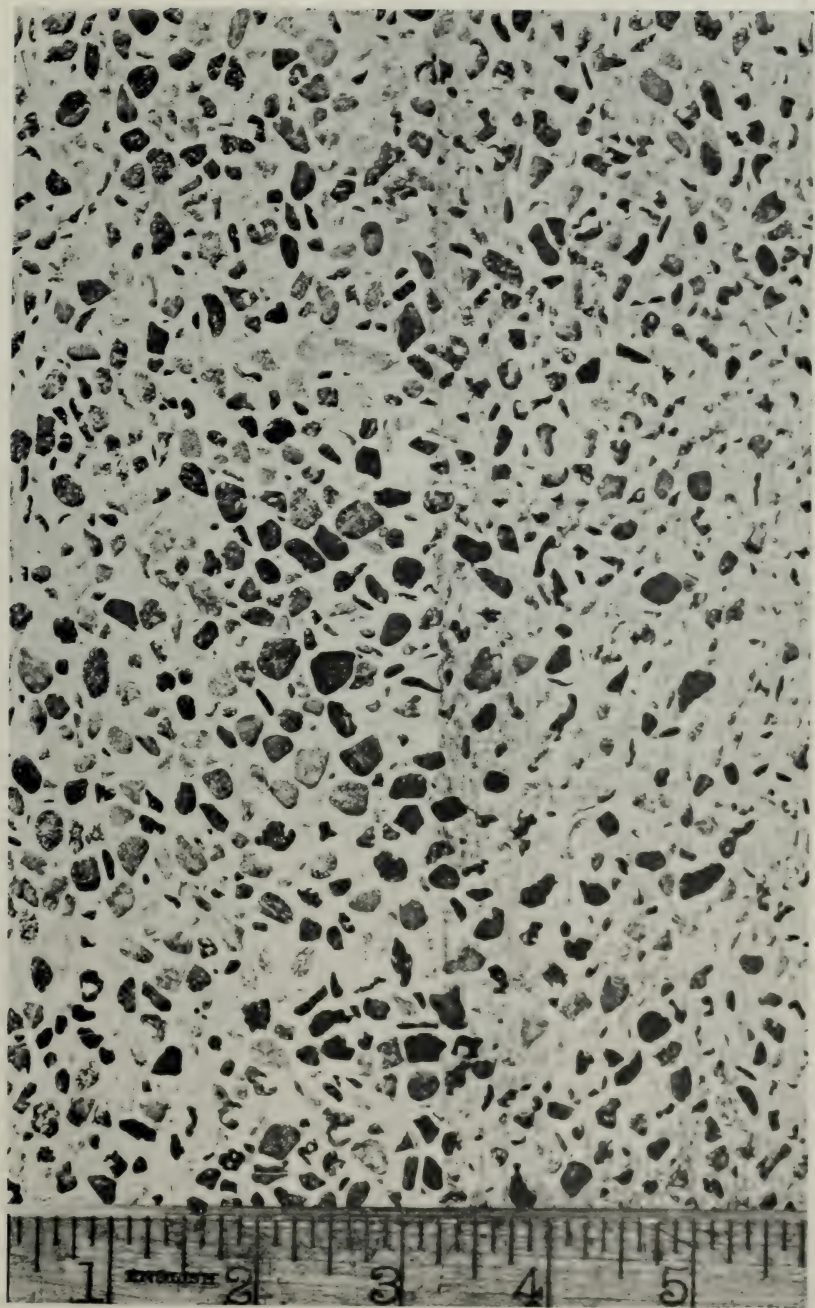
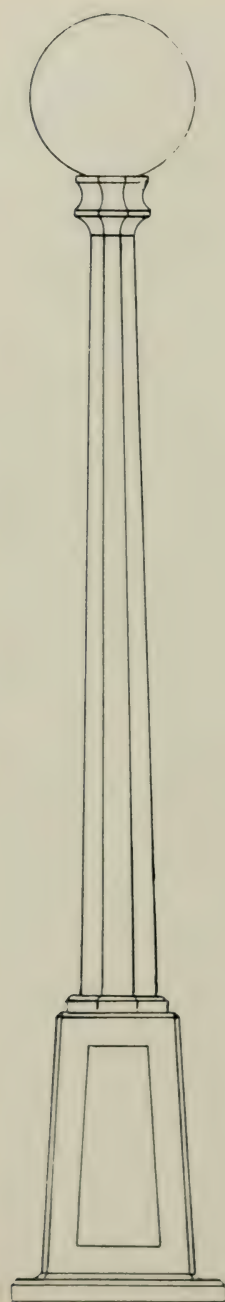
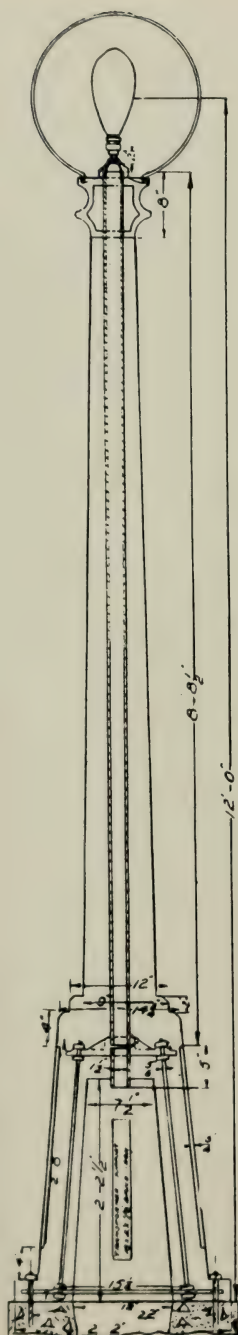


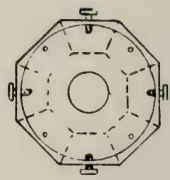
FIG. IV. FINISHED SURFACE OF CONCRETE POLE
SCALE IN INCHES



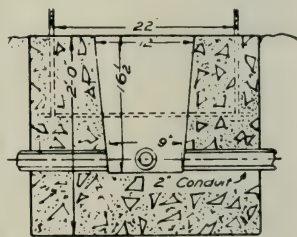
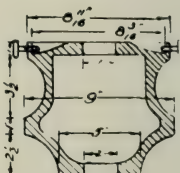
CONCRETE LAMP POST



DETAIL OF REINFORCEMENT



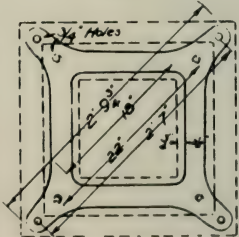
DETAIL OF SHADE HOLDER



CONCRETE SUB-BASE FOR POLE



TOP



C.I. REINFORCING PLATE BOTTOM

FIG. V. DIMENSIONS AND DETAILS

Concrete.—Two parts of cement to five parts of gravel were used in the preparation of the concrete. Several sample blocks of this mixture, eight inches in diameter and twelve inches long, were prepared and tested for compressive strength, and found to sustain from 3,000 to 4,350 pounds per square inch.

Design.—Complete dimensional data with details of the design are shown in Fig. V.

Molding.—A photograph of the mold used is shown in Fig. VI, with the iron pipe core in position. Great care must be exercised in pouring the concrete to keep the mixture uniform in all parts of the mold so as to avoid streaks and bands in the finished product. The length of time which the cement requires to set before the molds are removed depends on the dryness of the weather, the temperature, the consistency of the mixture, and to some extent the grade of cement used.



FIGURE VI. MOLD FOR CONCRETE POLES

In warm weather, molds filled in the afternoon could be removed early the following morning, while if the weather was cool and cloudy, better results were obtained by letting the molds stand for another half a day or more. No special harm is done by leaving the molds on longer than the most desirable period, except that it requires much more labor to secure the desired brush finish on the surface. If the molds are removed before the cement has had time to acquire a sufficient set, corners and other parts of the pole are apt to come off with the molds and disfigure the cast or require much patching to make it usable. The poles were made in the open air, but no doubt more uniform results could be obtained if the newly uncovered casts were under shelter and had protection from the direct rays of the sun.

Finishing.—The question of finishing concrete surfaces for artistic effects has been a subject of extended experiments, by different Portland cement associations. With a view of eliminating the objections to the lifeless, gray color of natural concrete, a series of experiments were made by introducing coloring matter while the mortar was being mixed, but the results were not encouraging. By using a dark-colored gravel, a pleasing contrast to the natural grayish background of the cement is obtained.



FIG. VII. FIRE ALARM AND POLICE STATION BOXES ATTACHED TO
CONCRETE POLE

The satisfactory appearance of the concrete surface depends chiefly upon its finish, rather than upon any given color or texture. The best finish was secured by removing the molds while the concrete was still quite green, and then carefully brushing the surface with steel brushes. After the surface has been carefully brushed and allowed to stand a few days, the monotonous, dull gray color effect may be readily removed by washing with a dilute acid, followed by a liberal rinsing with water through a hose. The rinsing must be thoroughly done before the acid has time to dry, or the surface will have a mottled, streaky appearance, little better in appearance than the original surface before applying the acid treatment. The strength of the acid solution did not seem to be important, but one part of commercial hydrochloric acid to two or three parts of water gave good results.

Handling.—One important advantage of concrete poles is the possibility of manufacturing the finished article near its final location. To distribute the poles over the campus a suitable frame was placed on a low wheeled cart. The method employed for handling the poles is readily seen from Figures VIII and IX.



FIG. VIII. RIG FOR MOVING POLES



FIG. IX. PLACING POLE IN POSITION

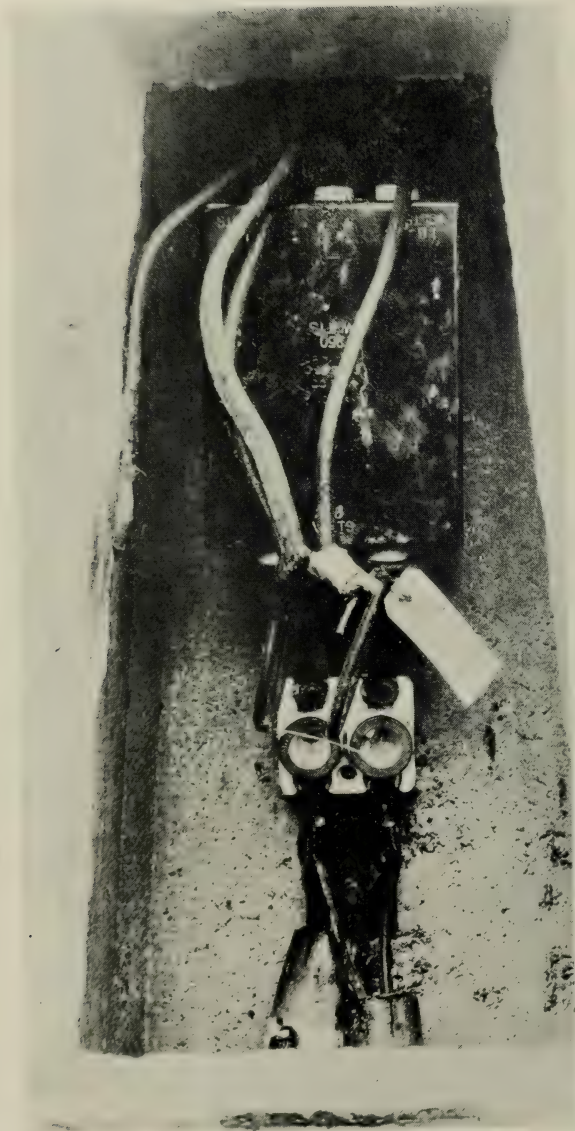


FIG. X
SMALL TRANSFORMER IN BASE OF POLE

Globes.—For the poles made in 1911, clear glass globes 20 inches in diameter were used. It was later determined that 18 inch globes of "Nuglass" gave satisfactory results. With translucent glass, the globe becomes a secondary source of illumination. This improves the appearance of the light standard and protects the eye against the intense brightness of the tungsten filament.

Electrical Data.—Electric power for campus lighting is obtained from 60-cycle alternators in the University power house and distributed at 2,300 volts. The current is conducted through lead-covered cables in underground fiber ducts to six distributing concrete-lined manholes. 6 by 8 feet square, and 8 to 12 feet deep, depending on the contour of the ground. At these distributing points the voltage is transformed from 2,300 volts to 240, by means of subway type transformers with $2\frac{1}{2}\%$, 5%, $7\frac{1}{2}\%$, and 10% taps to take care of varying degree drop in the feeders. From twenty to thirty poles are connected to each distributing manhole. No. 8 Duplex, 600-volt, lead-covered cable is used for the 240-volt secondary distribution. The cable is in a two-inch fiber conduit with $\frac{3}{8}$ -inch walls. In the base of each pole is a transformer (Fig. X), by which the voltage is reduced from 240 volts to 18.2 or 36.4 volts, depending upon whether a hundred candlepower or a two hundred candlepower lamp is used.

The above solution of the problem was probably the best that could be made with the type of lamps available at the time the poles were installed. Under present conditions, economy would be effected by using series lamps with compensating reactances on the 240-volt secondary distribution.



FIG. XI. FROM THE STEPS OF DENNY HALL
UNIVERSITY OF WASHINGTON

Cost.—The cost of labor and material for a concrete pole at the point of manufacture, excluding the globe, transformer, lamp and overhead charges, was, both in 1911 and 1914, \$14.50. The cost of iron poles of a somewhat similar plain pattern used by the City of Seattle was about \$36.00, without any trimmings, or about $2\frac{1}{2}$ times the cost of the concrete poles on the University campus. Disregarding overhead charges, the cost for the pole in place ready to give service and including the lamp, globe and special transformer, was, for 1911, \$38.50, and in 1914 \$36.70. This does not include the underground cable and conduit distributing system from the power house to the lamps.

Maintenance.—The maintenance expense, as well as the first cost of the concrete poles, is low in comparison to iron posts. The surface of the concrete on the campus poles shows practically no deterioration after eight years of service. The concrete surface does not scale, crack, or corrode. Two years ago a few of the poles were washed with soap and water to remove soot and dirt. The exposed iron on the plate forming the moveable panel in the base, and the iron shade holder have required much more attention than the concrete. The usual difficulties have been experienced in finding a paint that would effectively prevent the rusting of the iron.



FIG. XI. FROM THE STEPS OF DENNY HALL
UNIVERSITY OF WASHINGTON

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The Engineering Experiment Station includes all the bureaus and departmental groups previously active in engineering and industrial research, as well as the field occupied by individual investigators.

The scope of the work is twofold:

(a) To investigate and to publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural and industrial affairs;

(b) To undertake extended research and to publish reports on engineering and scientific problems.

The purpose of the station is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems. Every effort will

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1. FOREST PRODUCTS.

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2. MINING AND METALLURGY.

This division represents the field of the College of Mines, and includes cooperative work with the Seattle Mining Experiment Station of the United States Bureau of Mines.

3. CHEMICAL ENGINEERING AND INDUSTRIAL CHEMISTRY.

This division represents the application of chemistry to engineering and industrial problems.

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This division covers the field of the Department of Civil Engineering, with emphasis on hydraulic and sanitary engineering and the testing of road and structural materials.

5. ELECTRICAL ENGINEERING.

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7. PHYSICS STANDARDS AND TESTS.

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Inquiries in regard to the work of the Engineering Experiment Station should be addressed to the Director.

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ENGINEERING EXPERIMENT STATION SERIES

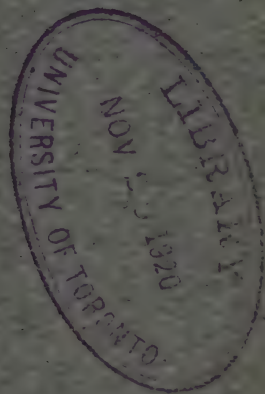
BULLETIN No. 7

Multiplex Radio Telegraphy and Telephony

BY

FRANCIS M. RYAN, J. R. TOLMIE AND ROY O. BACH

Graduate Students in Electrical Engineering



SEATTLE, WASHINGTON
PUBLISHED QUARTERLY BY THE UNIVERSITY
JULY, 1920

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1. Forest Products
2. Mining and Metallurgy
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UNIVERSITY OF WASHINGTON
ENGINEERING EXPERIMENT STATION

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MULTIPLEX RADIO TELEGRAPHY AND TELEPHONY.*

BY FRANCIS M. RYAN, J. R. TOLMIE AND ROY O. BACH

Various methods have been described for the simultaneous reception with a single antenna of radio signals from more than one transmitter. Similar methods have been recorded for multiplex transmission. These methods of multiplexing may be classified as follows:

(1) Those employing several radio frequencies and obtaining selectivity by means of radio frequency tuning.

(2) Methods using a single radio frequency and several tone frequencies, selectivity being obtained by audio frequency tuning.

(3) The use of a single radio frequency modulated by several intermediate frequencies each of which has been modulated by an audio frequency. Selectivity is obtained in this case by tuning at the intermediate frequencies.

The principal example of (1) is the divided antenna method employed by Marconi for both transmission and reception¹ and which may be used for either telegraphy or telephony. Method (2) has been used by the Telefunken Company¹, but has never proven satisfactory owing to difficulties arising from strays. Obviously this method is not applicable to telephony. The third method was originated by Mr. R. A. Heising² and is applicable to both telegraphy and telephony. Although somewhat more complicated than method (1) it is superior in so far as secrecy of transmission is concerned. A consideration of the effect of modulation shows that this method utilizes a considerable range of radio frequencies.

Let $\omega_1=2\pi x$ (Carrier frequency)

$\omega_2=2\pi x$ (Modulation frequency)

i =Antenna Current.

I_1 =Amplitude of the carrier frequency.

I_2 =Amplitude of the modulation frequency.

k =A constant depending on the degree of modulation.

Then $i = I_1 \sin \omega_1 t$

But I_1 is variable, $I_1 = I_2 \sin \omega_2 t + k$

$$i = I_2 \sin \omega_1 t \sin \omega_2 t + k \sin \omega_1 t$$

$$i = \frac{I_2}{2} \cos (\omega_1 - \omega_2) t - \frac{I_2}{2} \cos (\omega_1 + \omega_2) t + k \sin \omega_1 t$$

*Published in the Proceedings of the Institute of Radio Engineers, 1920

1. Zeemeek, Wireless Telegraphy, p. 325.

2. Craft and Colpitts, Radio Telephony, Proc. A. I. E. E., March 1919.

From this last equation it is apparent that not only the carrier frequency will be present, but also the sum and difference of the carrier and modulation frequencies. Each of these frequencies will be further broadened by voice or other audio frequency modulation. The intermediate frequencies used are of the order of 30 kilo-cycles per second and therefore the antenna must operate at radio frequencies differing by about 60 kilo-cycles per second. This is not possible at wave lengths exceeding about 400 meters without the use of some special device in the antenna circuit.

From these considerations it would seem that the most simple and practical method of multiplexing a radio system is the use of several radio frequencies, that is, method (1). In order to successfully employ a number of radio frequencies in the same antenna circuit, it is necessary that the antenna be resonant to each of the frequencies, that is that its reactance be zero for the particular frequencies used. This may be accomplished by the use of certain types of impedance networks in series with the antenna. Figure 1 shows the simplest application of this method. The antenna circuit is given zero reactance for two frequencies by the loop L_1C_1 coupled to the antenna by the common inductance L_1' . Figure 2 shows the equivalent lumped circuit. In this circuit the low frequency antenna capacity is assumed lumped at C_a . L_a is made equal to the sum of the inductance of the two coupling coils (and load coil if one is used) plus one third the inductance of the antenna for uniform current.³ The capacity of the actual antenna is most satisfactorily measured by means of an impedance bridge. If then the natural wave length of the antenna is measured the inductance of the antenna may be calculated. At the transmitter the two radio frequency sources may be loosely coupled to the antenna by means of the coils P_1 and P_2 as shown in Fig. 1. The frequencies of these sources must, of course, correspond to the two points of zero reactance for the antenna circuit. At the receiver P_1 and P_2 would be secondary coils forming parts of two closed circuits, one tuned to each of the frequencies to be received. The coupling in both the transmitter and receiver must be quite loose in order that the points of zero reactance may not be shifted or additional ones introduced.

In a circuit such as shown in Figs. 1 and 2 neglecting resistance the loop reactance is:

$$X_1 = \frac{\omega L_1' - \omega^3 C_1 L_1 L_1'}{1 - \omega^2 L_1 C_1 - \omega^2 L_1' C_1}$$

³ Circular 74 Bureau of Standards, p. 73

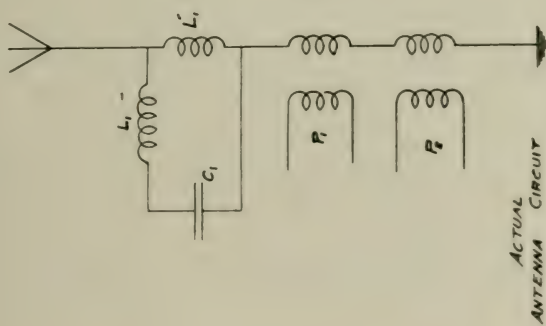
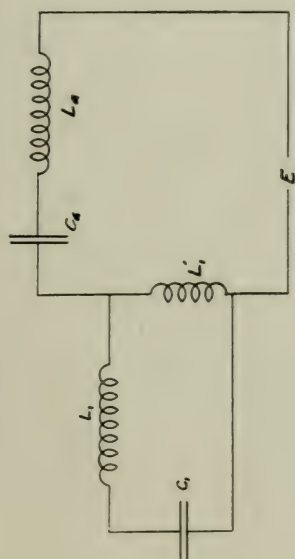


FIG. 1



EQUIVALENT CIRCUIT

FIG. 2

The antenna reactance is:

$$X_a = \frac{\omega^2 L_a C_a - 1}{\omega C_a}$$

The total reactance of the circuit then is:

$$X_t = \frac{\omega^2 L_a C_a - 1}{\omega C_a} + \frac{\omega L_1' - \omega^3 C_1 L_1 L_1'}{1 - \omega^2 L_1 C_1 - \omega^2 L_1' C_1} \quad (2)$$

The design of such a duplex antenna is much simplified by tuning the loop and antenna circuits independently to the same frequencies. The following familiar relations then hold:

$$K = \frac{L_1'}{\sqrt{(L_1 + L_1') (L_a + L_1')}}}$$

Where k = Coupling Coefficient

$L_a + L_1'$ = Total antenna inductance.

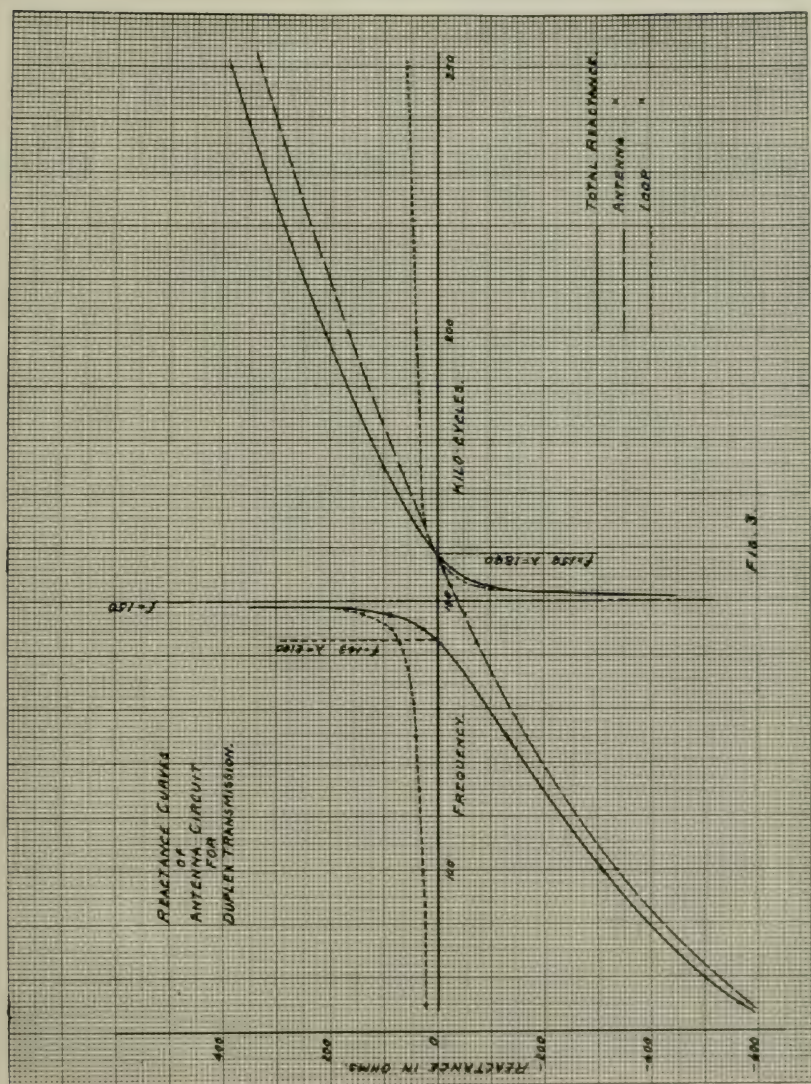
$L_1 + L_1'$ = Total loop inductance.

$$f_1 = \frac{f}{\sqrt{1+k}} \quad (3)$$

$$f_2 = \frac{f}{\sqrt{1-k}} \quad (4)$$

Where f is the frequency to which the antenna and loop have been independently tuned, and f_1 and f_2 are the frequencies for which the reactance is zero.

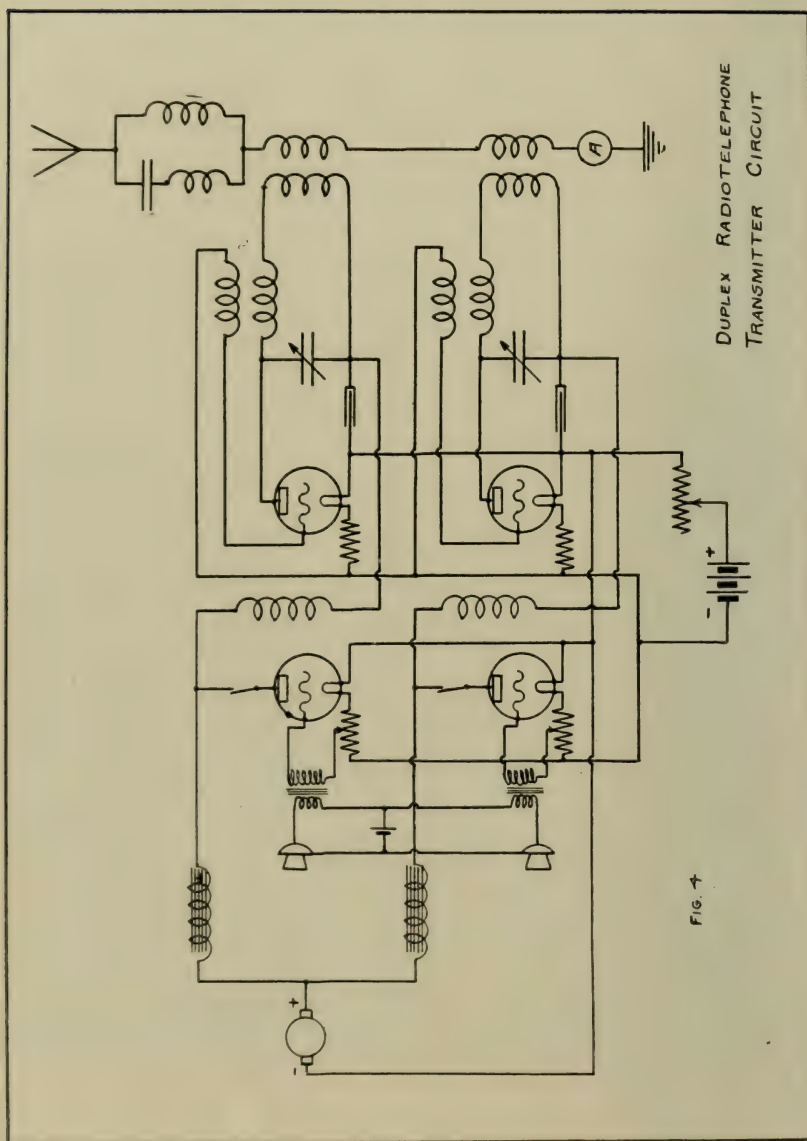
In order to test the practicability of such a method, a duplex radio telephone transmitter was installed in the Electrical Engineering Laboratory of the University of Washington. The constants of the antenna circuit used are given in Table I. The reactance of the equivalent antenna circuit has been calculated for various frequencies and the results are shown graphically in Fig. 3. The dotted line shows the loop reactance, the dash line the antenna reactance and the full line the reactance of the complete circuit. Two points of zero reactance are to be noted, at 143 and 159 kilo-cycles per second corresponding to wave lengths of 2,100 and 1,890 meters, respectively.



KAUFFEL & BERKE CO., NEW YORK, N.Y. 100 C.B.

TABLE I

C_a	=0.00283	Microfarads.
C_l	=0.00250	"
L_1	= 42.1	Microhenries.
L_a	=356.	"
L_l	=408.	"

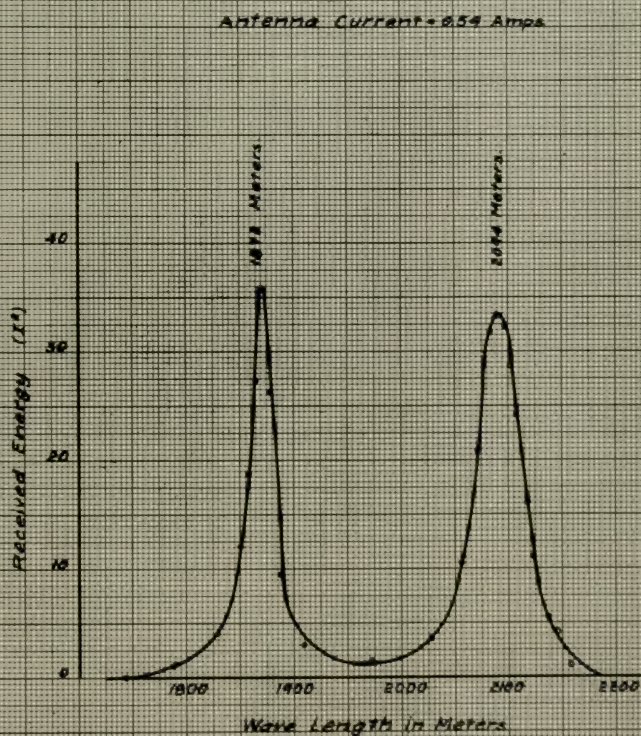


The actual circuit employed in the transmitter is shown in Fig. 4. Western Electric type E vacuum tubes were used both for generation and modulation, the Heising system of modulation being employed.⁴ A check of the frequency and wave length of the emitted

4. Craft and Colpitts, Radio Telephony, Proc. A. I. E. E. March 1919, p. 360.

waves was obtained by taking a resonance curve (Fig. 5) with a decremeter placed in inductive relation to the transmitting antenna. The two waves as measured differ less than one percent from the calculated values. The resonance curve is for the unmodulated waves.

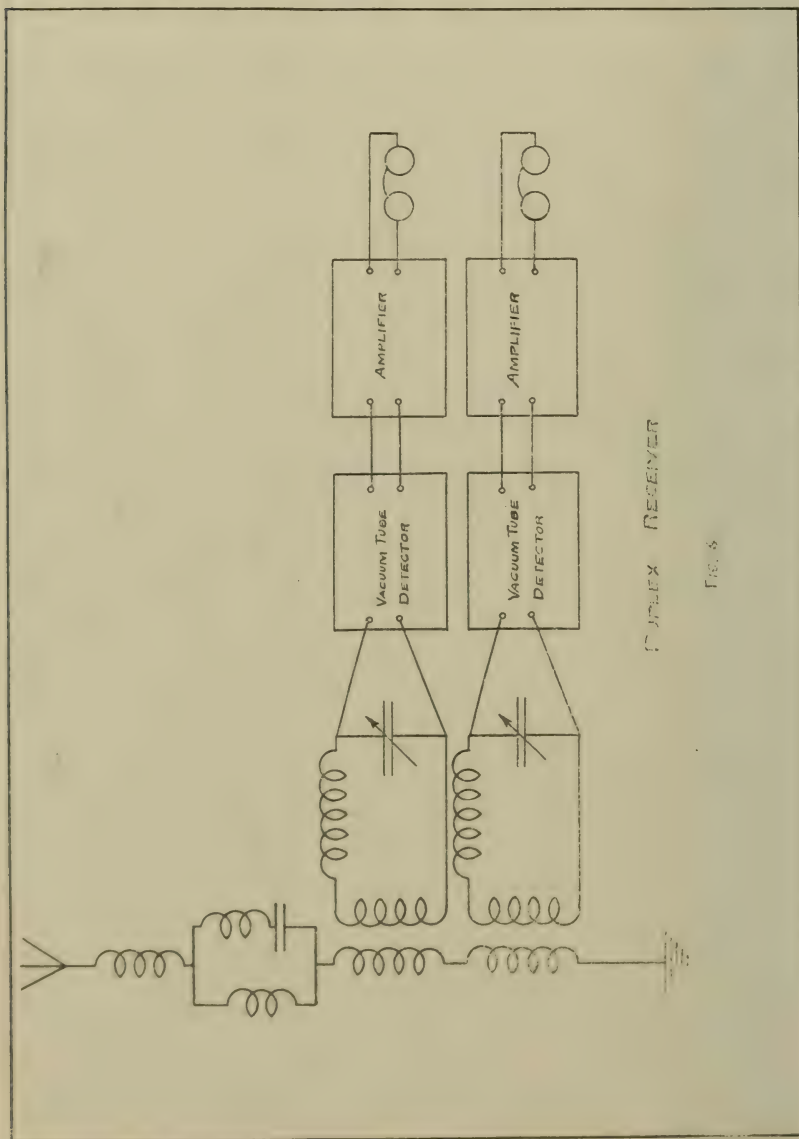
A working test was obtained by installing a duplex receiver at the Seattle Y. M. C. A., about five miles (8 Km.) distant from the Uni-



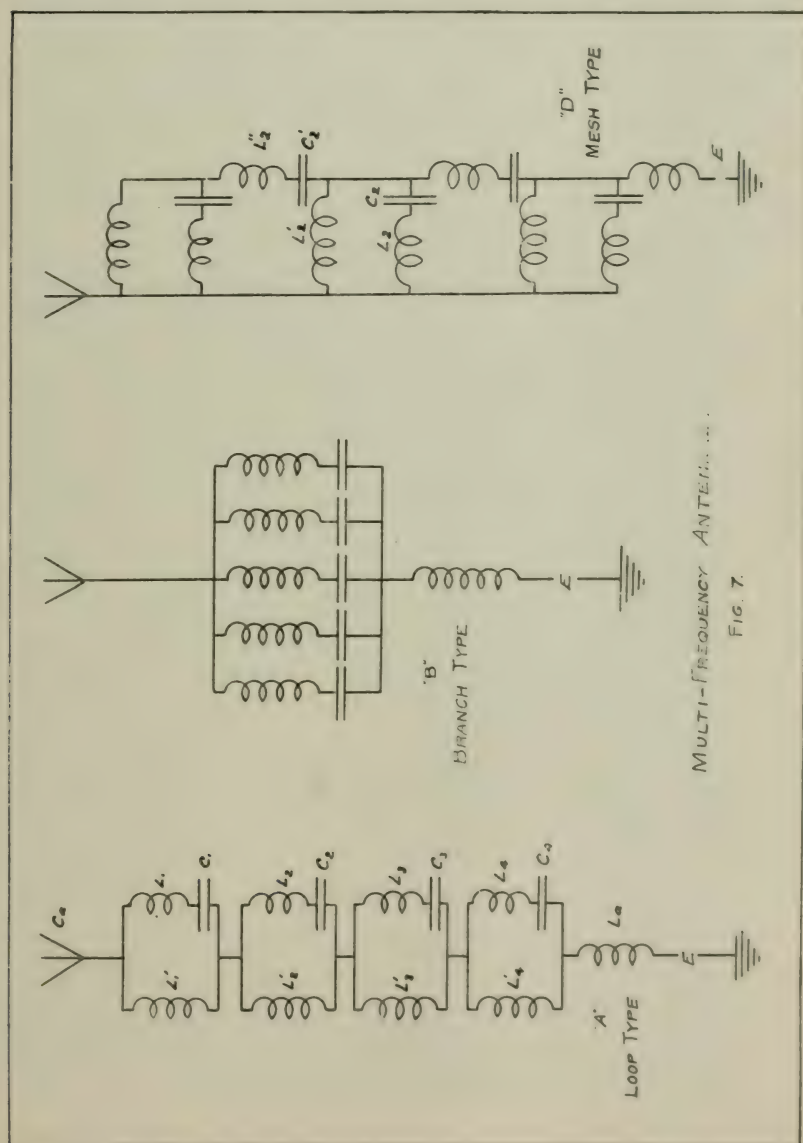
RESONANCE CURVE
OF
DUPLEX RADIO TELEPHONE

Fig. 5.

versity. The circuits used are shown schematically in Fig. 6. The design of the antenna circuit was similar to that at the transmitter. Two wire telephone lines were available during part of the tests and were used for talking back to the University as no transmitting apparatus was installed at the Y. M. C. A. With this arrangement two people at the Y. M. C. A. could converse with two others at the Uni-



versity with practically no cross talk between the two waves used. Other tests were made allowing a phonograph to play on one of the wave lengths while the other was used for talking. Practically perfect separation was obtained. It was found that a separation of about 15 kilo-cycles between the two carrier waves was the minimum which



could be satisfactorily used for telephony, but that for telegraphy the waves could be much closer together.

The successful completion of these tests suggested that further experiments be conducted with a greater number of frequencies. There are many networks that can be used to give the antenna the desired characteristics. Three typical ones are shown in Fig. 7. The Series Loop Type shown in Fig. 7A gives one more point of zero reactance than there are loops in series with the antenna. The Branch type, Fig. 7B, has as many points of zero reactance as there are branches in the network. The number of points given by the Mesh type, Fig. 7D, is equal to twice the number of units, a unit being defined as consisting of a loop such as $L_2'L_2C_2$ and a series part such as $L_2''C_2'$ between loops.

The Series Loop type of network seems to offer the greatest flexibility and ease of design and was the most thoroughly investigated. An experimental network of this type used with an actual antenna to give five points of zero reactance was set up in the University laboratory. The circuit constants used are given in Table II, the notation referring to Fig. 7A. The antenna was excited by five independent vacuum tube generators inductively coupled to the antenna circuits. The coupling coils were inserted in series at the point *E* in Fig. 7A. Fig. 8 is a photograph of this "set up." The network is seen on the table at the left and the generator circuits and coupling coils on the table in the background. When using a single tube for each generator, the operation was somewhat critical due to reactions caused by coupling to the antenna circuit. This was overcome by using a small oscillator tube and an amplifier power tube for each of the five waves. The frequencies delivered were then independent of what kind of a system the amplifier tube fed, and depended only on the constants of the circuits of the oscillator tubes.

TABLE II

$C_a = 0.00127$	Microfarads.	$L_2' = 213.$	Microhenries.
$L_a = 314.$	Microhenries.	$L_3' = 179.$	"
$L_1 = 428.$	"	$L_4' = 157.$	"
$L_2 = 522.$	"	$C_1 = 0.00148$	Microfarads.
$L_3 = 922.$	"	$C_2 = 0.00161$	"
$L_4 = 980.$	"	$C_3 = 0.00141$	"
$L_1' = 155.5$	"	$C_4 = 0.00173$	"

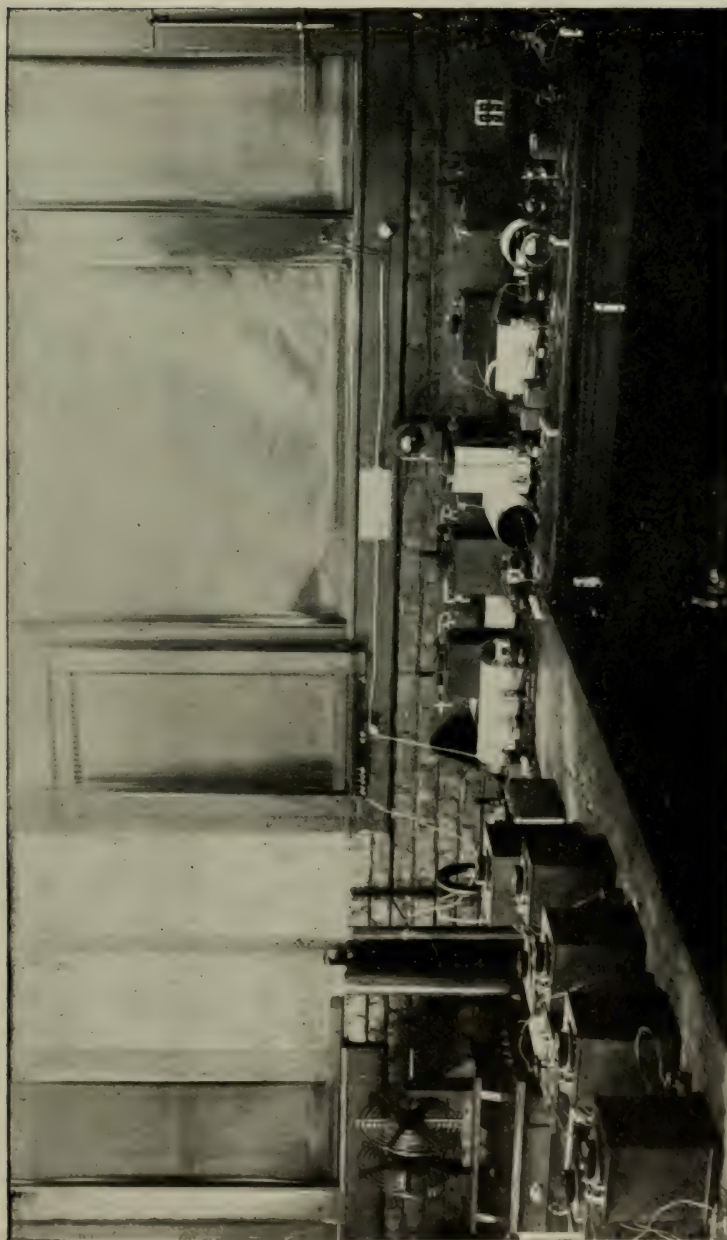
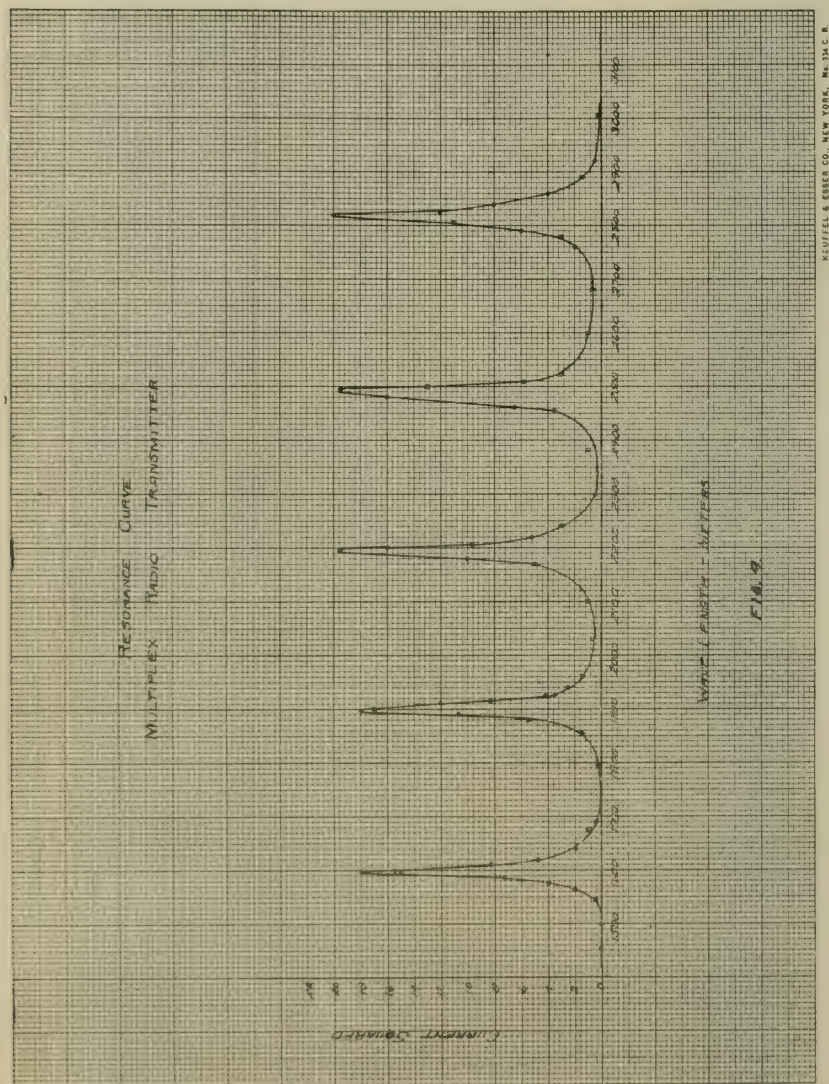


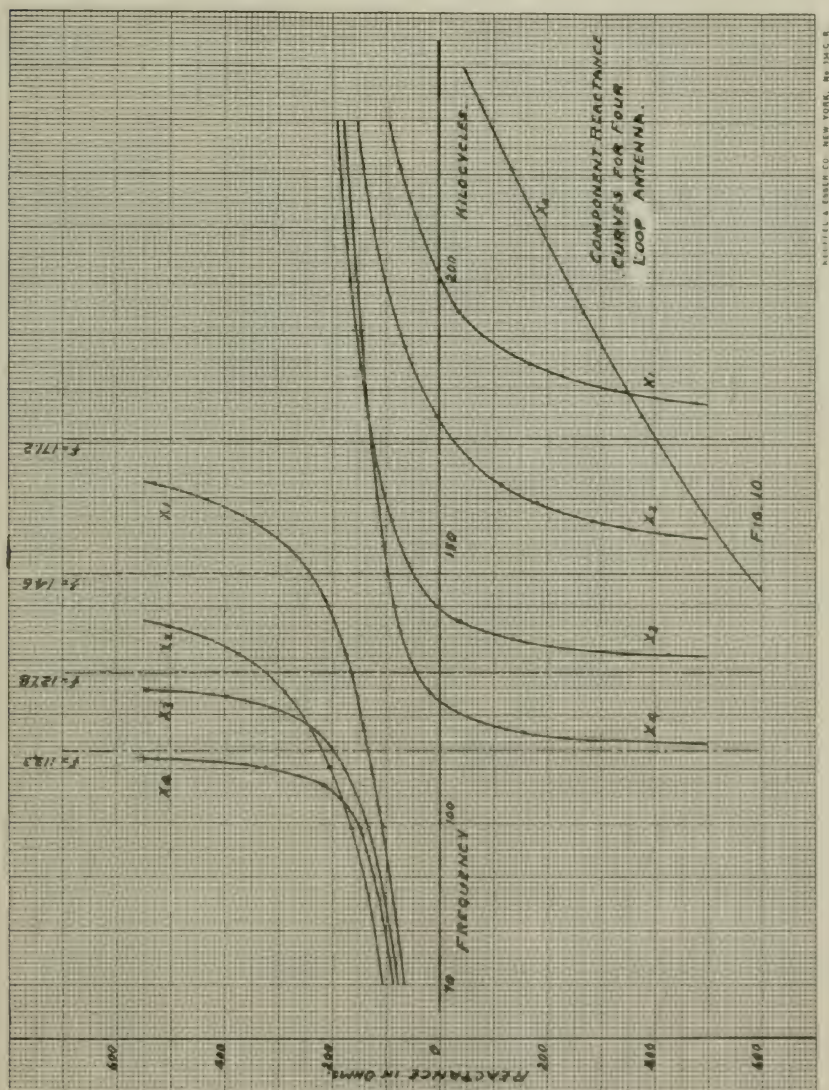
Fig. 8

The resonance curve shown in Fig. 9 was taken by bringing a decremeter in inductive relation to the antenna. The reactance of this antenna system has been computed for a number of frequencies



and the results plotted in Figs. 10 and 11. Fig. 10 gives the reactance curves of the separate loops and of the remainder of the circuit and Fig. 11 the reactance of the complete circuit. This last

curve is obtained by adding the five curves of Fig. 10 algebraically. The discontinuities or points of infinite reactance correspond to the natural frequencies of the loops and the points of zero reactance to the working points or frequencies which are to be radiated by the antenna.

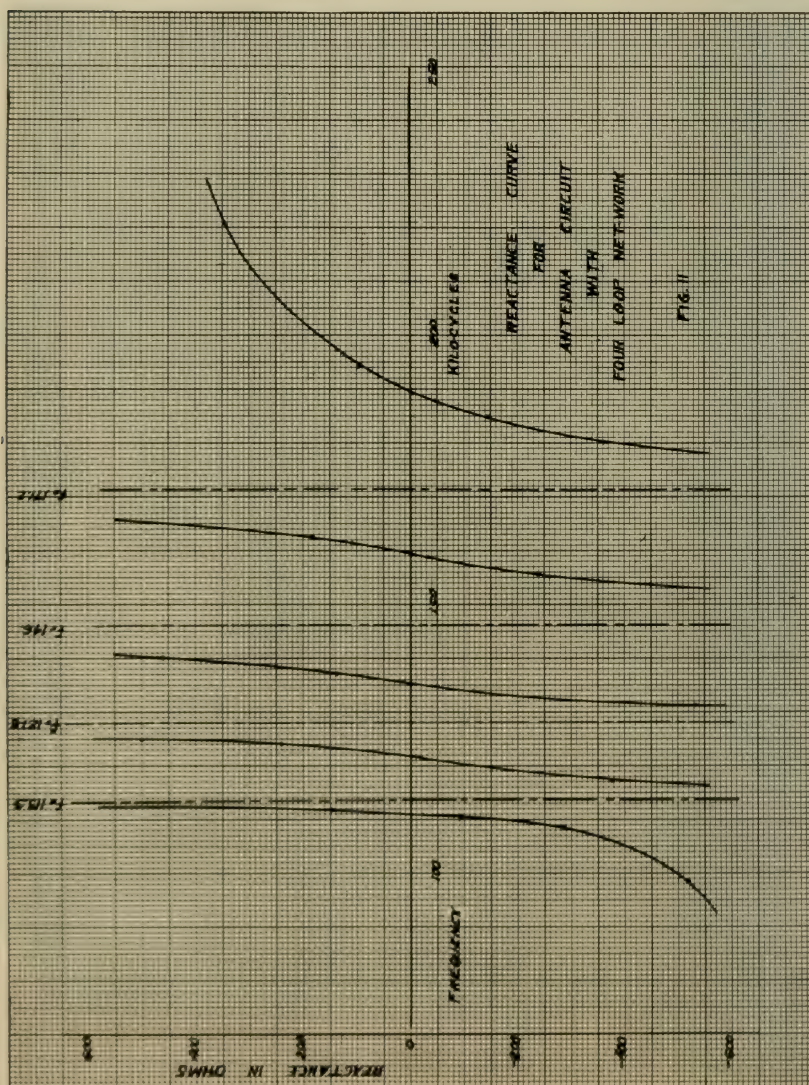


Equation (2) may be extended to apply to a network of this type having four loops by the addition of three more terms to repre-

sent the reactance of the additional loops. This equation then becomes:

$$\begin{aligned}
 X_1 = & \frac{\omega^2 L_a C_a - 1}{\omega C_a} + \frac{\omega L_1' - \omega^3 C_1 L_1 L_1'}{1 - \omega^2 C_1 L_1 - \omega^2 C_1 L_1'} + \frac{\omega L_2' - \omega^3 C_2 L_2 L_2'}{1 - \omega^2 C_2 L_2 - \omega^2 C_2 L_2'} \\
 & + \frac{\omega L_3' - \omega^3 C_3 L_3 L_3'}{1 - \omega^2 C_3 L_3 - \omega^2 C_3 L_3'} + \frac{\omega L_4' - \omega^3 C_4 L_4 L_4'}{1 - \omega^2 C_4 L_4 - \omega^2 C_4 L_4'} \quad (5)
 \end{aligned}$$

The notation refers to Fig. 7A.



In designing a network for use with a given antenna the problem resolves into one of determining the circuit constants necessary to give the points of zero reactance at the desired working frequencies or wave lengths. It will be shown how this may be done for a system having five points of zero reactance. Reducing to a common denominator equation (5) becomes:

$$X = \frac{A_0\omega^{10} + A_2\omega^8 + A_4\omega^6 + A_6\omega^4 + A_8\omega^2 + A_{10}}{A_1\omega^9 + A_3\omega^7 + A_5\omega^5 + A_7\omega^3 + A_9\omega} \quad (6)$$

Where:

$$A_0 = C_a [L_a a_1 a_2 a_3 a_4 + L_1' \beta_1 a_2 a_3 a_4 + L_2' a_1 \beta_2 a_3 a_4 + L_3' a_1 a_2 \beta_3 a_4 + L_4' a_1 a_2 a_3 \beta_4]$$

$$A_2 = -C_a [L_a (a_1 a_2 a_3 + a_1 a_2 a_4 + a_1 a_3 a_4 + a_2 a_3 a_4) + L_1' (\beta_1 a_2 a_3 + \beta_1 a_3 a_4 + \beta_1 a_2 a_4 + a_2 a_3 a_4) + L_2' (\beta_2 a_1 a_3 + \beta_2 a_1 a_4 + \beta_2 a_3 a_4 + a_1 a_3 a_4) + L_3' (\beta_3 a_1 a_2 + \beta_3 a_2 a_4 + \beta_3 a_1 a_4 + a_1 a_2 a_4) + L_4' (\beta_4 a_1 a_2 + \beta_4 a_2 a_3 + \beta_4 a_1 a_3) + a_1 a_2 a_3 a_4]$$

$$A_4 = C_a [L_a (a_1 a_2 + a_1 a_3 + a_1 a_4 + a_2 a_3 + a_2 a_4 + a_3 a_4) + L_1' (\beta_1 a_2 + \beta_1 a_3 + \beta_1 a_4 + a_2 a_3 + a_2 a_4 + a_3 a_4) + L_2' (\beta_2 a_1 + \beta_2 a_3 + \beta_2 a_4 + a_1 a_3 + a_1 a_4 + a_3 a_4) + L_3' (\beta_3 a_1 + \beta_3 a_2 + \beta_3 a_4 + a_1 a_2 + a_1 a_4 + a_2 a_4) + L_4' (\beta_4 a_1 + \beta_4 a_2 + \beta_4 a_3 + a_1 a_2 + a_1 a_3 + a_2 a_3) + a_1 a_2 a_3 + a_1 a_2 a_4 + a_1 a_3 a_4 + a_2 a_3 a_4]$$

$$A_6 = -C_a [L_a (a_1 + a_2 + a_3 + a_4) + L_1' (\beta_1 + a_2 + a_3 + a_4) + L_2' (a_1 + \beta_2 + a_3 + a_4) + L_3' (a_1 + a_2 + \beta_3 + a_4) + L_4' (a_1 + a_2 + a_3 + \beta_4) + a_1 a_2 + a_1 a_3 + a_1 a_4 + a_2 a_3 + a_2 a_4 + a_3 a_4]$$

$$A_8 = C_a [L_a + L_1' + L_2' + L_3' + L_4'] + a_1 + a_2 + a_3 + a_4$$

$$A_{10} = -1$$

$$A_1 = C_a a_1 a_2 a_3 a_4$$

$$A_3 = -C_a [a_1 a_2 a_3 + a_1 a_2 a_4 + a_1 a_3 a_4 + a_2 a_3 a_4]$$

$$A_5 = C_a [a_1 a_2 + a_2 a_3 + a_1 a_3 + a_2 a_4 + a_1 a_4 + a_3 a_4]$$

$$A_7 = -C_a [a_1 + a_2 + a_3 + a_4]$$

$$A_9 = C_a$$

$$a_1 = C_1 L_1 + C_1 L_1'$$

$$a_2 = C_2 L_2 + C_2 L_2'$$

$$a_3 = C_3 L_3 + C_3 L_3'$$

$$a_4 = C_4 L_4 + C_4 L_4'$$

$$\beta_1 = C_1 L_1$$

$$\beta_2 = C_2 L_2$$

$$\beta_3 = C_3 L_3$$

$$\beta_4 = C_4 L_4$$

In order that the effective resistance of the antenna system may not be excessive the natural frequencies of the loops must differ considerably from the working frequencies, that is, it is desirable to place the points of infinite reactance about midway between those of zero reactance. The points of infinite reactance are determined by the roots of the denominator of equation (6) equated to zero. If R_1 , R_2 , R_3 , and R_4 are the squares of the respective values of ω for which the reactance is desired infinite, then the following relations satisfy the condition that the denominator equals zero, thereby fixing the infinite points.

$$\begin{aligned} a_1 &= \frac{1}{R_1} \\ a_2 &= \frac{1}{R_2} \\ a_3 &= \frac{1}{R_3} \\ a_4 &= \frac{1}{R_4} \end{aligned} \tag{7}$$

This group of equations determines the values of a_1 , a_2 , a_3 , and a_4 , and when the frequencies for which the reactance is to be infinite are decided upon the a 's become numerics and their values may be substituted in the numerator.

The frequencies for which the reactance is zero are determined by the roots of the numerator of equation (6) equated to zero. If the squares of the values of ω for which the reactance is desired zero are r_1 , r_2 , r_3 , r_4 and r_5 , then the following relations follow from the theory of equations.

$$\begin{aligned} \frac{A_2}{A_0} &= -(r_1 + r_2 + r_3 + r_4 + r_5) \\ \frac{A_4}{A_0} &= r_1 r_2 + r_1 r_3 + r_1 r_4 + r_1 r_5 + r_2 r_3 + r_2 r_4 + r_2 r_5 + r_3 r_4 \\ &\quad + r_3 r_5 + r_4 r_5 \end{aligned}$$

$$\begin{aligned}
\frac{A_6}{A_0} &= -(r_1 r_2 r_3 + r_1 r_2 r_4 + r_1 r_2 r_5 + r_1 r_3 r_4 + r_1 r_3 r_5 + r_1 r_4 r_5 \\
&\quad + r_2 r_3 r_4 + r_2 r_3 r_5 + r_2 r_4 r_5 + r_3 r_4 r_5) \\
\frac{A_8}{A_6} &= r_1 r_2 r_3 r_4 + r_1 r_3 r_4 r_5 + r_1 r_2 r_4 r_5 + r_1 r_2 r_3 r_5 \\
&\quad + r_2 r_3 r_4 r_5 \\
\frac{A_{10}}{A_0} &= -r_1 r_2 r_3 r_4 r_5
\end{aligned} \tag{8}$$

This group consists of five simultaneous equations in the unknowns $\beta_1, \beta_2, \beta_3, \beta_4, L_a, L_1', L_2', L_3', L_4'$ and C_a . Five of these may be given arbitrary values providing care is taken not to choose values which lead to physically impossible solutions. It has been found convenient to give values to $\beta_1, \beta_2, \beta_3$, and β_4 , and solve for L_a, L_1', L_2', L_3' , and L_4' in terms of C_a . The solution may then be carried out by means of determinants.

Equation (5) may be extended to apply to a general case giving $n/2$ points of zero reactance and having $n/2 - 1$ loops in circuit.

$$\begin{aligned}
X_i &= \frac{\omega^2 L_a C_a - 1}{\omega C_a} + \frac{\omega L_1' - \omega^3 L_1 C_1 L_1'}{1 - \omega^2 L_1 C_1 - \omega^2 L_1' C_1} + \dots \\
&\quad + \dots + \frac{\omega L_m' - \omega^3 L_m C_m L_m'}{1 - \omega^2 L_m C_m - \omega^2 L_m' C_m}
\end{aligned} \tag{9}$$

And reducing to a common denominator equation (9) becomes of the following general form:

$$X_i = \frac{A_0 \omega^n + A_2 \omega^{n-2} + A_4 \omega^{n-4} + \dots + A_{n-2} \omega^2 + A_n}{A_1 \omega^{n-1} + A_3 \omega^{n-3} + A_5 \omega^{n-5} + \dots + A_{n-3} \omega^3 + A_{n-1} \omega} \tag{10}$$

The coefficients A_0, A_1, A_2 , etc., are functions of the electrical constants of the system as in the case of the four loop network. The roots of the denominator equated to zero merely show that the points of infinite reactance occur whenever the frequency is equal to the natural frequency of one of the loops. In a manner similar to that shown for the four loop network equations may be set up relating the

roots and the coefficients of the numerator. There will be $n/2$ of these equations an n variables. In general this system of equations will be indeterminate, but by reducing the complexity of the network or by imposing certain arbitrary conditions upon it, the system will become determinate. The complexity of the network may be reduced by removing the inductance from the capacity sides of the loops. This is not usually advantageous as it often leads to inconvenient magnitudes for the remaining circuit constants. Arbitrary values may be assigned (within limits) to $\beta_1, \beta_2, \beta_3$, etc., as in the four loop case, and then the values of L_a, L_1', L_2' etc., may be determined in terms of C_a . The solution is then applicable to any suitable antenna. The values of L_1', L_2', L_3' , etc., can be assigned and solution made for $L_a, \beta_1, \beta_2, \beta_3$, etc., if desired.

Equation (10) can be written in the following condensed form:

$$X_i = \frac{\sum_{q=0}^n A_{2q} \omega^{n-2q}}{\sum_{q=2p+1}^{n-1} A_q \omega^{n-q}} \quad (11)$$

The equivalent expansion for the branch type network will be:

$$X_i = \frac{\sum_{q=2p+1}^{n-1} A_q \omega^{n-q+2}}{\sum_{q=0}^n A_{2q} \omega^{n-2q}} \quad (12)$$

Equation (12) differs from the reciprocal of equation (11) only in the degree of the odd terms. If, however, the series loop type of circuit, Fig. 7A, contains capacity in both branches of the loop its reactance is given by equation (12) instead of equation (11). The mesh type of circuit shown in Fig. 7D gives a reactance expansion similar to equation (11).

The following numerical solution of an antenna with a two loop network is given to illustrate the methods of design and calculation of multifrequency circuits. The results were checked experimentally to show the degree of accuracy that might be expected.

The desired working frequencies were chosen to correspond to wave lengths of 1600, 1900 and 2200 meters. The frequencies for

infinite reactance i.e., the frequencies of the respective loops, were taken to correspond to wavelengths of 1750 and 2050 meters. β_1 and β_2 , i. e., the product of inductance and capacity on the condenser side of the loops, were selected for wavelengths of 1550 and 1850 meters.

It is first necessary to obtain the equation for the total reactance of the entire network. This is as follows:

$$X^t = \frac{\omega^2 L_a C_a - 1}{\omega C_a} + \frac{\omega L_1' - \omega^3 L_1 C_1 L_1'}{1 - \omega^2 L_1 C_1 - \omega^2 L_1' C_1} + \frac{\omega L_2' - \omega^3 L_2 C_2 L_2'}{1 - \omega^2 L_2 C_2 - \omega^2 L_2' C_2} \quad (13)$$

In a manner exactly similar to that previously shown for the four loop network three simultaneous equations are obtained from equation (13).

$$L_a [a_1 + a_2 + \frac{A_2}{A_0} a_1 a_2] + L_1' [a_2 + \beta_1 + \frac{A_2}{A_0} a_2 \beta_1]$$

$$+ L_2' [a_1 + \beta_2 + \frac{A_2}{A_0} a_1 \beta_2] = - \frac{a_1 a_2}{C_a}$$

$$L_a [1 - \frac{A_4}{A_0} a_1 a_2] + L_1' [1 - \frac{A_4}{A_0} a_2 \beta_1] + L_2' [1 - \frac{A_4}{A_0} a_1 \beta_2]$$

$$= - \frac{a_1 + a_2}{C_a}$$

$$L_a a_1 a_2 \frac{A_6}{A_0} + L_1' a_2 \beta_1 \frac{A_6}{A_0} + L_2' a_1 \beta_2 \frac{A_6}{A_0} = - \frac{1}{C_a}$$

These equations are of the following form:

$$L_a a_1 + L_1' b_1 + L_2' c_1 = K_1 / C_a$$

Where

$$a_1 = -5.21983 \times 10^{-12} \quad b_1 = -4.35003 \times 10^{-12} \quad c_1 = -4.41122 \times 10^{-12}$$

$$a_2 = -2.17443 \times 10^{-12} \quad b_2 = -1.49029 \times 10^{-12} \quad c_2 = -1.58529 \times 10^{-12}$$

$$a_3 = -1.02424 \times 10^{-12} \quad b_3 = -0.80364 \times 10^{-12} \quad c_3 = -0.8343 \times 10^{-12}$$

$$k_1 = -1.02155 \times 10^{-24}$$

$$k_2 = -2.04676 \times 10^{-12}$$

$$k_3 = -1$$

Solving these equations by determinants for L_a , L_1' and L_2'
We obtain

$$L_a = \frac{0.00884 \times 10^{-12}}{C_a \times 0.01227} \quad \text{For } C_a = 0.00283 \text{ Micro. fds.}$$

$$L_1' = \frac{0.002398 \times 10^{-12}}{C_a \times 0.01227} \quad L_1' = 69 \quad " \quad "$$

$$L_2' = \frac{0.00264 \times 10^{-12}}{C_a \times 0.01227} \quad L_2' = 76 \quad " \quad "$$

The values L_1 , L_2 , C_1 and C_2 are then found from the known values of a_1 , a_2 , β_1 and β_2 .

TABLE III

λ Assumed	λ Experimental	% Error
1600	1620	1.25
1900	1900	0.00
2200	2260	2.72

The discrepancies observed in the experimental check are probably due to the effect of long leads and to the fact that some of the constants were measured at audio frequencies.

The previous equations may be considerably simplified by making $\beta_1 = \beta_2 = L_a C_a$. A network of this type was set up and checked experimentally. The results obtained are as follows.

TABLE IV

λ Assumed	λ Experimental	% Error
1600	1605	0.31
1900	1905	0.21
2200	2208	0.36

It is believed that such systems of multiplexing by means of multi-frequency antennae will be of considerable value for fleet communication in the Navy. It should also prove valuable in marine coast stations designed to connect ship radio telephone stations with

the existing land wire telephone system. Another possible application is that of transoceanic communication at long wave lengths.

In high power stations the output is often limited by the corona voltage of the antenna. It is to be noted that in using a multi-frequency antenna for multiplex transmission the maximum instantaneous voltage will be the arithmetic sum of the maximums of the several frequencies impressed. This will occur at a relatively low frequency but demands consideration. Another limitation of the methods proposed is the lack of flexibility of adjustment. The effective resistance of such networks becomes excessive when it is attempted to place the working waves very close together. Some additional work should be done studying the effective resistance and efficiency of multi-frequency antennae. In spite of these limitations the method will probably find considerable application in special instances.

The writers are deeply indebted to Dr. C. E. Magnusson and Prof. L. F. Curtis of the Electrical Engineering Department of the University of Washington for the excellent facilities provided for the experiments described and for their interest in the work. Thanks is also due to Mr. V. I. Kraft of the Seattle Y. M. C. A. for his generosity in allowing the use of their antenna and premises. It should also be mentioned that the Navy Department through Lieutenant Commander Frank Luckel District Communication Superintendent at the Navy Yard, Puget Sound, very kindly extended the privilege of using the transmitter. The Office of the Chief Signal Officer of the Army cooperated by furnishing the necessary vacuum tubes without which the experiments would have been impossible.

University of Washington, Seattle, Wash.

December 16, 1919.

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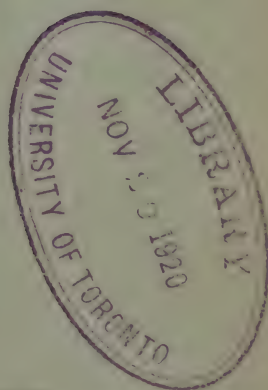
BULLETIN No. 8

Voltage Wave Analysis with
Indicating Instruments

BY

LESLIE FORREST CURTIS

Assistant Professor of Electrical Engineering



SEATTLE, WASHINGTON
PUBLISHED QUARTERLY BY THE UNIVERSITY
JUNE, 1920

THE Engineering Experiment Station of the University of Washington was established in December, 1917, in order to coördinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

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VOLTAGE WAVE ANALYSIS WITH INDICATING INSTRUMENTS

INTRODUCTION

THE investigation outlined in the following pages and the construction of the instrument called by the author an "Harmonimeter" were inspired by the lack of a satisfactory workable standard of wave form.

Perhaps the best previous attack was made in 1894 by Dr. M. I. Pupin in a paper before the American Institute of Electrical Engineers¹ in which he outlined a method for resonating harmonics and measuring their amplitude by means of an electrostatic voltmeter in parallel with an adjustable condensance. The very large inductances and the very small capacitances necessary for a sensitive indication on the electrostatic voltmeter make his method undesirable. As shown by the author, much more definite readings may be obtained with the circuit described below, which may also be more easily duplicated.

At a later date fixed combinations of constants for use as standards were suggested and discussed.^{2, 3, 4, 5 and 6.} Each of the proposed standards produces resonance only by chance and its indications are therefore almost always misleading.

When the results are to be used entirely with reference to telephone circuits, the objections to the fixed constants are partially met in the "Telephone Interference Standard."⁷ It gives, however, only relatively good or bad indications. No accurate estimate of the number, order or amplitude of the harmonics present may be obtained with it.

In the absence of oscillograms, it is necessary to produce actual resonance of each harmonic generated within the machine before its worst behavior as a source of distortion of wave form can be predicted. Even when oscillograms are taken for non-resonant conditions, (as on open circuit), many of the higher harmonics escape detection. Therefore it is maintained that only an adjustable set of reactances in connection with some indicating device which can produce and detect sharp resonance over the whole range of objectionable frequencies is satisfactory in investigating wave forms.

The method outlined below gives no indication of the relative phase positions of the components and therefore no accurate indication of the maximum value of the resultant wave. When

applied to circuits of distributed inductance and capacitance this information would often be misleading since the phase positions of the harmonics change with respect to each other along the circuit. With any wave, phase position is important only with the lower harmonics, the third and the fifth. Therefore it is felt that this is the least important of the three harmonic characteristics of a wave. The solution for the others is given below.

It is the purpose of this paper to present a workable method for determining the order and amplitude of the components of a wave using telephone condensers, air core inductances and a sensitive hot-wire galvanometer. An instrument is also described which gives a direct scale reading for the order of the harmonics up to the 99th in a sixty cycle system and an easy means of calculating their amplitudes. The first part of the paper was presented by the author before the American Institute of Electrical Engineers in Los Angeles in September 1919.⁸

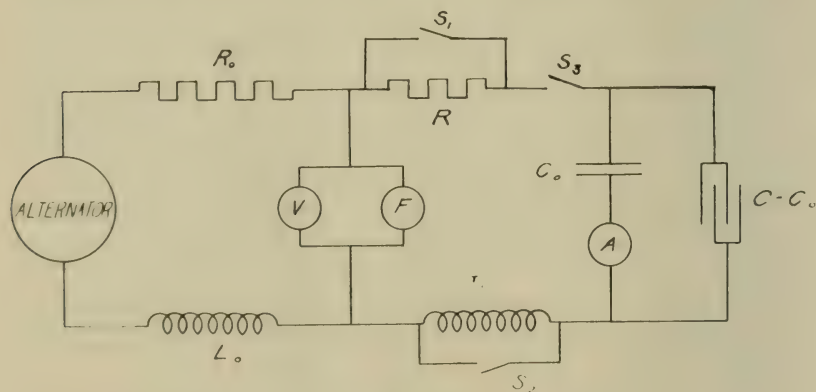


FIG. 1.

METHOD

The method is based on the well known use of the wave meter, but adapted to low frequencies and with this important difference,—a fundamental frequency is always present, may not be neglected, and must be treated simultaneously with the other harmonics. It is that of obtaining resonant conditions for the n th harmonic in the generated voltage by several separate adjustments of inductance and capacitance. When resonance has been obtained, a second reading is taken with added series resistance.

The diagram of connections used is shown in Fig. 1. The alternator supplying the wave to be tested is assumed to have an inductance L_o and a resistance R_o . Resistance R and inductance L may be added to the circuit at will by means of switches S_1 and S_2 . V and F indicate a voltmeter and a frequency meter connected to the machine at all times. On closing switch S_3 an adjustable capacitance $C-C_o$ is connected in the circuit. In parallel with this is a small fixed condenser C_o , the current in which may be measured by a small hot-wire current-squared meter A of negligible resistance. C is the total capacitance. The voltmeter is read only when S_3 is open.

For a given initial voltage and frequency the resonant points for the harmonics are indicated by maxima in the deflections of meter A . If R_o is not sufficient for protection of the condenser from abnormal voltages at resonance, more resistance may be added and considered as a part of the generator. If L_o is not sufficient to produce resonance of the lower harmonics with the amount of capacitance C available, more inductance may be added and considered as a part of the generator.

The calculation consists of two parts; the determination of the order of the harmonics present and the calculation of their amplitude. Table I gives a summary of the notation used in the calculations.

TABLE I.

NOTATION

L	Known inductance.
L_o	Inductance of generator and leads.
R	Known resistance.
R_o	Resistance of generator and leads.
C_o	Known fixed condensance.
$C-C_o$	Adjustable known condensance.
C	Total condensance.
ω	Angular velocity of fundamental wave.
n	Order of harmonic.
nE	Effective n th harmonic in generated voltage.

TABLE I.—*Continued.*

NOTATION

${}_nP$	Ratio of harmonic to fundamental.
E	Effective value of resultant voltage.
${}_nI$	Effective n th harmonic in current in main circuit.
I	Effective value of resultant current.
A	Effective value of current in C_0 circuit.
D	Deflection of hot-wire meter.
${}_nR$	Value of R_0 for n th harmonic.
${}_nX$	Reactance of circuit to n th harmonic.
K, k, M, N and Q .	Constants.
${}_nE_c$	Effective n th harmonic voltage across C .
E_c	Resultant voltage across C .
S	Arbitrary scale for harmonimeter condensance.
T	Arbitrary scale for harmonimeter inductance.

ORDER OF THE HARMONICS

The order of the harmonics present may be found from the values of total capacitance, C_1 and C_2 , necessary to produce resonance with and without the known inductance L in series.

In the first case

$$L_0 n \omega + L n \omega = \frac{1}{C_1 n \omega} \quad (1)$$

and in the second

$$L_0 n \omega = \frac{1}{C_2 n \omega} \quad (2)$$

from which

$$n = \frac{1}{\omega} \sqrt{\frac{1/C_1 - 1/C_2}{L}} \quad (3)$$

If the result is not exactly a whole number it may be corrected as it is known that n must be an integer and probably odd. If another harmonic is present, its order may be determined in the same way from new adjustments of capacitance, C_3 and C_4 , with and without the inductance L . An alternative method is to continue the curve upon which C_1 or C_2 produced resonance

after one of the harmonics has been determined and take one additional reading of capacitance for the resonance of the other harmonic.

In this case

$$L_o \omega = \frac{1}{C_2 n^2 \omega} \quad (4)$$

and

$$L_o n' \omega = \frac{n'}{C_2 n^2 \omega} = \frac{1}{C_4 n' \omega} \quad (5)$$

from which

$$n' = n \sqrt{C_2 / C_4} = n \sqrt{C_1 / C_3} \quad (6)$$

AMPLITUDE OF THE HARMONICS

Having found the order of the harmonics present it is easy to determine their amplitude by taking additional readings of the current squared meter at resonance with a known resistance inserted in the circuit.

In order to introduce no errors due to currents in circuits in parallel with the capacitance and to necessitate no correction therefor, no change should be made in the load or connections when reading the hot-wire meter except to introduce the resistance R . The voltmeter and frequency meter should be connected to the machine terminals.

For resonance of the n th harmonic and with no series resistance

$$L_o \omega = \frac{1}{C n^2 \omega} \quad (4)$$

$${}_1I = \frac{{}_1E}{\sqrt{{}_1R^2 + \left(\frac{1}{C n^2 \omega} - \frac{1}{C \omega} \right)^2}} \quad (7)$$

$${}_3I = \frac{{}_3E}{\sqrt{{}_3R^2 + \left(\frac{{}_3}{C n^2 \omega} - \frac{1}{{}_3 C \omega} \right)^2}} \quad (8)$$

and

$${}_nI = {}_nE / {}_nR = {}_1E \cdot {}_nP / {}_nR \quad (9)$$

It will be noted that the resistance of the circuit is assumed to depend upon the frequency of the harmonic. In practice it is shown that the resistance increases with the frequency. In

most cases the resistances ${}_1R$, ${}_3R$, etc., are so small compared to the other terms under the radical that they may be neglected.

With this approximation

$${}_1I = \frac{{}_1E}{\frac{1}{C n^2 \omega} - \frac{1}{C \omega}} = \frac{{}_1E}{{}_1X} \quad (10)$$

and

$${}_3I = \frac{{}_3E}{\frac{3}{C n^2 \omega} - \frac{1}{3C \omega}} = \frac{{}_3E}{{}_3X} = \frac{{}_1E {}_3P}{{}_3X} \quad (11)$$

$$\text{Now } I = \sqrt{{}_1I^2 + {}_3I^2 + \dots nI^2 + \dots} \quad (12)$$

$$\text{therefore } I = {}_1E \sqrt{1/{}_1X^2 + {}_3P^2/{}_3X^2 + \dots nP^2/nR^2 + \dots} \quad (13)$$

The resultant generated voltage E is

$$\begin{aligned} E &= \sqrt{{}_1E^2 + {}_3E^2 + \dots nE^2 + \dots} \\ &= {}_1E \sqrt{1 + {}_3P^2 + \dots nP^2 \dots} \end{aligned} \quad (14)$$

and when no harmonic exceeds 10 per cent of the fundamental, ${}_1E$ may be replaced by E with less than 1 per cent of error.

Now

$$I = \frac{A C}{C_o} \quad (15)$$

therefore with (13)

$$\frac{A_1^2 C^2}{E^2 C_o^2} = \frac{1}{{}_1X^2} + \frac{{}_3P^2}{{}_3X^2} \dots + \frac{{}_nP^2}{{}_nR^2} + \dots \quad (16)$$

A_1 being obtained from the deflection D_1 of the meter and its calibration constant.

When a resistance R is placed in series a new reading D_2 is obtained and the corresponding equation is

$$\frac{A_2^2 C^2}{E^2 C_o^2} = \frac{1}{{}_1X^2} + \frac{{}_3P^2}{{}_3X^2} + \dots \frac{{}_nP^2}{({}_nR + R)^2} + \dots \quad (17)$$

$$\text{therefore } {}_nP^2 = {}_nR^2 \left(\frac{A_1^2 C^2}{E^2 C_o^2} - \frac{1}{{}_1X^2} - \frac{{}_3P^2}{{}_3X^2} - \dots \right) \quad (18)$$

$$\text{and } {}_nP^2 = ({}_nR + R)^2 \left(\frac{A_2^2 C^2}{E^2 C_o^2} - \frac{1}{{}_1X^2} - \frac{{}_3P^2}{{}_3X^2} - \dots \right) \quad (19)$$

Now usually all terms except those containing constants of the fundamental and the n th harmonic are negligible, therefore by close approximation

$${}_nP^2 = {}_nR^2 \left(\frac{A_1^2}{E^2 C_o^2} - \frac{1}{{}_1X^2} \right) \quad (20)$$

and

$${}_nP^2 = ({}_nR + R)^2 \left(\frac{A_2^2}{E^2 C_o^2} + \frac{1}{{}_1X^2} \right) \quad (21)$$

from which numerical values of ${}_nR$ and ${}_nP$ may be obtained. If the other terms are appreciable, an approximate solution may be made by equations (20) and (21) for all of the harmonics and then it may be corrected by means of equations (18) and (19).

Further reductions to eliminate ${}_nR$ and give equations more convenient for rapid use are made as follows:—

$$\begin{aligned} {}_1X &= \frac{1}{C n^2 \omega} - \frac{1}{C \omega} \\ &= \frac{1}{C \omega} \left(\frac{n^2 - 1}{n^2} \right) \end{aligned} \quad (22)$$

$$\frac{1}{{}_1X^2} = \frac{C^2 \omega^2 n^4}{(n^2 - 1)^2} = C^2 N \quad (23)$$

$$\text{where} \quad N = \frac{\omega^2 n^4}{(n^2 - 1)^2} \quad (24)$$

Substitute (23) in (20) and (21) and

$${}_nP^2 = {}_nR^2 C^2 \left(\frac{A_1^2}{E^2 C_o^2} - N \right) \quad (25)$$

and

$${}_nP^2 = ({}_nR + R)^2 C^2 \left(\frac{A_2^2}{E^2 C_o^2} - N \right) \quad (26)$$

It is convenient to let

$$\frac{A_1^2}{E^2 C_o^2} = KM_1 \quad \text{and} \quad \frac{A_2^2}{E^2 C_o^2} = KM_2 \quad (27 \text{ and } 28)$$

where K is a constant depending upon the value of C_o and M is a factor which may be plotted for each voltage in terms of the

deflection D of the instrument, and which includes its calibration constant.

$$\text{Thus } {}_n P^2 = {}_n R^2 C^2 (K M_1 - N) \quad (29)$$

$$\text{and } {}_n P^2 = ({}_n R + R)^2 C^2 (K M_2 - N) \quad (30)$$

Eliminate ${}_n R$ and solve for ${}_n P$ and

$${}_n P = \frac{R C (K M_1 - N)^{\frac{1}{2}} (K M_2 - N)^{\frac{1}{2}}}{(K M_1 - N)^{\frac{1}{2}} - (K M_2 - N)^{\frac{1}{2}}} \quad (31)$$

$$= \frac{R C Q_1 Q_2}{Q_1 - Q_2} \quad (32)$$

$$\text{where } Q = \sqrt{K M - N} \quad (33)$$

SENSITIVENESS OF INDICATION

There are several things which influence the sensitiveness of the indication. Previous experimenters have shown methods whereby the reading of the generator current or the condenser voltage was required. The first indication is inaccurate and often misleading and the second is not very sensitive. It will be shown that the indication of the ammeter in the shunt condenser circuit is the best for practical use.

Consider first the amplification possible or the ratio of the magnitude of the n th harmonic component to that of the fundamental. For the generator current

$${}_n I = {}_1 E {}_n P / {}_n R \quad (9)$$

$$\text{and from (10) } {}_1 I = {}_1 E C \omega n^2 / (1 - n^2) \quad (34)$$

From (9) and (34)

$${}_n I / {}_1 I = {}_n P (1 - n^2) / {}_n R C \omega n^2 \quad (35)$$

or when n is large

$${}_n I / {}_1 I = {}_n P / {}_n R C \omega \quad (36)$$

For the votages across the condenser

$${}_n E_c = {}_1 E {}_n P / {}_n R C n \omega \quad (37)$$

and

$${}_1 E_c = E n^2 / (1 - n^2) \quad (38)$$

from which

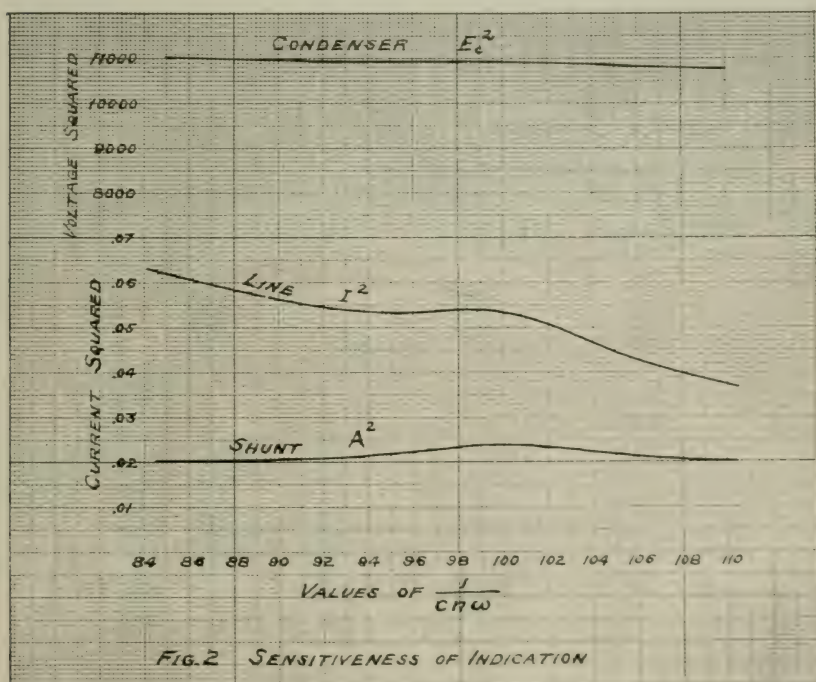
$${}_n E_c / {}_1 E_c = {}_n P (1 - n^2) / {}_n R C n^3 \omega \quad (39)$$

or when n is large

$${}_n E_c / {}_1 E_c = {}_n P / {}_n R C n \omega \quad (40)$$

It may be easily shown that the ratio of the components of current in the shunt circuit is the same as that in (35).

All of the above equations indicate that the smaller the value of the capacitance, the more sensitive the indication. With very large inductances and small condensers an electrostatic voltmeter may be used across the condenser. The sensitiveness is then as in equation (39), but if an ammeter is used as an indicator either in the main or shunt circuit the sensitiveness is n times as great or that in equation (35).



For small percentages of the harmonic component, the meter in the main circuit may give a very poor or even no indication of a maximum when the harmonic is brought into resonance. This is true because as the capacitance is changed to produce resonance the fundamental component of the current in the generator circuit is almost proportional to it. In the shunt circuit the fundamental component is almost constant and the resonance of the harmonic is easily detected. These facts may best be shown by an actual calculation.

Consider the following case:— ${}_1E=100$, $n=5$, ${}_nP=0.005$, ${}_nR=5.0$, $L\omega=20.0$, and $1/C_o\omega=750.0$. The values of the fundamental, fifth harmonic and resultant currents squared in the main and shunt circuits, and the voltages squared across the condenser are given in Table II. Curves corresponding to the meter readings are given in Fig. 2.

The maximum of current in the main circuit is hardly distinguishable and occurs for a value of $1/Cn\omega$ of 98.6 while the resonance of the harmonic is at 100.0 ohms. If the resistance of the circuit had been greater or the percentage of the harmonic less, no maximum would have been indicated. No maximum can be detected in the condenser voltage. On the other hand a decided maximum is shown in the resultant current in the shunt circuit, a rise of about 18 per cent being indicated at approximately 100 ohms reactance.

Thus it is seen that the indication of an ammeter in the shunt condenser circuit is more sensitive and accurate than any other. The circuit is easily obtained with types of apparatus most often available.

TABLE II

EXAMPLE TO SHOW SENSITIVENESS OF INDICATION

$1/Cn\omega$	${}_1I^2$	${}_5I^2$	I^2	${}_1E_c^2$	${}_5E_c^2$	E_c^2	${}_1A^2$	${}_5A^2$	A^2
85	0.0610	0.0010	0.0620	11010	7	11020	0.0196	0.0002	0.0198
90	0.0541	0.0020	0.0561	10960	16	10970	0.0195	0.0007	0.0202
95	0.0483	0.0050	0.0533	10900	45	10940	0.0194	0.0020	0.0214
98	0.0453	0.0086	0.0539	10870	83	10950	0.0193	0.0037	0.0230
100	0.0432	0.0100	0.0532	10850	100	10950	0.0193	0.0044	0.0237
102	0.0417	0.0086	0.0503	10830	90	10920	0.0192	0.0040	0.0232
105	0.0392	0.0050	0.0442	10810	55	10860	0.0192	0.0024	0.0217
110	0.0356	0.0020	0.0376	10770	24	10790	0.0191	0.0011	0.0202

THE HARMONIMETER

The form of the equations suggested the possibility of developing a commercial meter which would give direct indications of the order of the harmonics and easily calculated values of their amplitudes. An apparatus was therefore constructed by the author which is collectively called an "Harmonimeter." The units consist of the fixed condenser, the adjustable condenser with scales, and a calibrated variometer for giving any desired initial and added inductance.

The fixed condenser C_0 is arranged in five sections for connection to the meter as in Fig. 3. These sections were made by connecting in series portions of two Western Electric 21AA telephone condensers which were unwrapped until the desired capacitance was obtained. The whole group was hermetically sealed. Telephone jacks and a plug are used for connection with the meter, which is provided with a short-circuiting button normally closed. It will be noted that the capacitance between terminals is always 0.8 microfarad while that in the meter circuit is 0.8, 0.4, 0.2, 0.1 or 0.05 microfarad, depending on the position of the plug. The whole group, together with socket terminals for the current-squared meter, is mounted in a box as shown at the left in the photograph (Fig 4.). The constant K for use in the equations is given on the box opposite each jack. For the de-

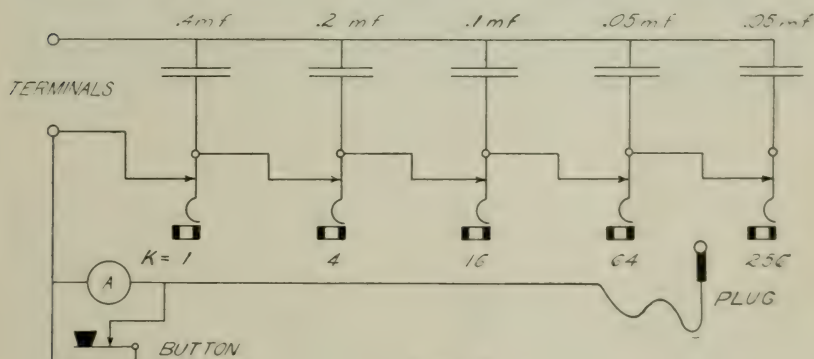


FIG. 3.

tection of very small percentages of harmonics it is possible to use a telephone receiver in place of the hot-wire meter.

The use of the different capacitances in the meter circuit connected by means of the plug switch has a decided advantage over a resistance shunt in parallel with the meter for reducing the scale deflections for heavy currents. It eliminates changes in calibration due to poor contact at the meter terminals and has a low total effective resistance.

The resistance of the meter alone is 7 ohms. If its scale deflection were reduced to one quarter of the original value (one half the current through the meter), the effective resistance of the meter and shunt would be 3.5 ohms. In the above method however, by changing the tap from 0.8 to 0.4 microfarad the effective resistance is reduced to 1.75 ohms and full voltage is

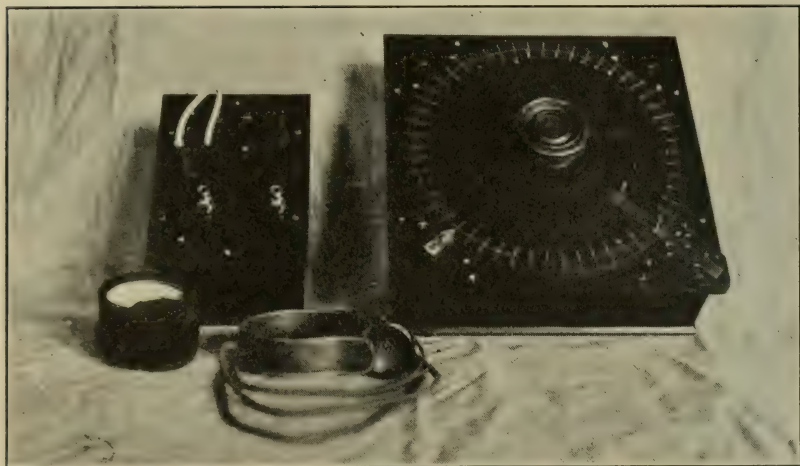


FIG. 4. FIXED AND ADJUSTABLE CAPACITORS

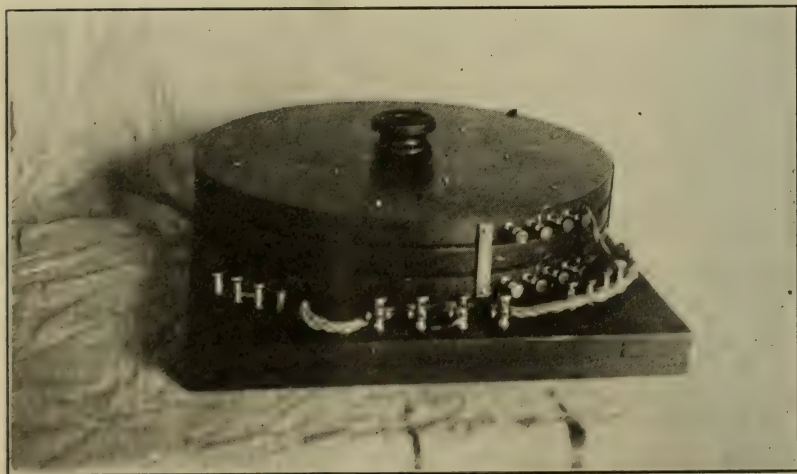


FIG. 5. VARIOMETER

effective at any connection which may have a tendency to give poor contact.

For the meter used, Table III gives the safe deflections (Roller Smith hot-wire galvanometer No. 61422) which may be allowed without exceeding a safe maximum voltage (1000 volts) on the condenser.

TABLE III
SAFE DEFLECTIONS OF METER

K	Harmonic	Safe D
1	All	All
4	All	All
16	All	All
64	3	37
64	5, etc.	All
256	3	9
256	5	26
256	7	52
256	9	85
256	11, etc.	All

The adjustable condensance is provided with a dial switch giving uniform variations of $1/C$ between steps when connected in parallel with the fixed condenser. The condensers for the above were adjusted in the same way as were those for the fixed condenser but in a bank of eight,—2.0, 1.0, 0.5, 0.25, 0.125, 0.0625, 0.03125 and 0.01563 microfarad respectively. The dial switch has 54 points with 8 contacts on each point. Such condensers as are necessary to make the required capacitance at each step are connected permanently to the contacts, the others being left blank. The capacitance on the first step (including the fixed condenser) is 4.39 microfarads and on the 54th, 0.894 microfarad, the intermediate points giving uniform variations of $1/C$. An arbitrary scale S is given for $1/C$, the maximum value being 1000. Thus the actual relation is expressed by

$$1/C = 1117 S \text{ darafs.} \quad (41)$$

For 60 cycles, $1/\omega$ is 0.00265 and equation (3) may be written

$$n = 0.00265 \sqrt{\frac{1117S_1 - 1117S_2}{L}} = 0.0885 \sqrt{\frac{S_1 - S_2}{L}} \quad (42)$$

from which

$$S_1 - S_2 = 127.5 L n^2 \quad (43)$$

Thus it is seen that the movement of the dial switch or the change in scale S to produce resonance a second time after changing the inductance by an amount L is proportional to this change in inductance and to the square of the order of the harmonic.

Movable harmonic scales free to turn about the scale S of the dial switch and graduated directly in terms of n for four values of added inductance L are provided. These are set on zero for the setting S_1 of the dial switch and give n directly for setting S_2 . The four scales thus formed are lettered A, B, C and D, and correspond to the changes in inductance or scale divisions of the variometer given in Table IV. The scales termed 2A, 2B, 4A, and 4B in Table IV are formed by multiplying the values given on scale A or B by 2 or 4 respectively.

TABLE IV
HARMONIC SCALES FOR VARIOMETER SETTINGS

Scale for n	Added L	Series	Variometer Divisions		
			2 groups of 4	4 groups of 2	Parallel
D	0.0738	20	..	..	..
C	0.0369	10	..	..	..
B	0.0185	5	20	..	..
A	0.0092	2.5	10	..	..
2B	0.0046	..	5	20	..
2A	0.0023	..	2.5	10	..
4B	0.00115	..	..	5	20
4A	0.00058	..	..	2.5	10

A photograph of the adjustable condenser with its scales is shown at the right in Fig. 4. The short pointer indicates the values on scale S . The long pointer may be moved in or out to read on any of the movable scales A, B, C or D, which may be turned about the center by the small knob.

For convenience in the use of these scales a variometer having a large inductance and capable of wide variation is provided. This consists of eight coils of No. 13 dec. copper wire wound in 26 layers of 10 turns each with an inside diameter of 3.5 inches. The coils are mounted astatically in pairs in four planes, those in alternate planes being capable of movement about a shaft between the pairs of coils. By placing the planes close together and using alternate stationary and movable planes very close coupling is obtained. The coils are arranged for grouping in any combination of series or parallel by binding post connections. The range of the inductance is given in Table V and the number of divisions

for use with the harmonic scales in Table IV. To facilitate its use in this connection, the scale of the variometer is divided into $2\frac{1}{2}$ per cent steps of the maximum and marked upon a scale (T) numbered from 6 to 40. Referring to Table V for the constant (k), the inductance at any setting may be expressed as

$$L = 0.0000577 kT \text{ henry.} \quad (44)$$

TABLE V
RANGE OF VARIOMETER

Connections	Constant	Henrys	
	k	Max.	Min.
All in series.....	64	0.1475	0.0222
2 parallel groups of 4.....	16	0.0369	0.0055
4 parallel groups of 2.....	4	0.0092	0.00138
All in parallel.....	1	0.0023	0.00035

A photograph of this variometer is shown in Fig. 5. The complete harmonimeter wired for use appears as in Fig. 8.

The values of M for use in the calculation of Q in equation (33) are given for voltages from 100 to 130 and for meter deflections (Roller-Smith H. W. Galvanometer No. 61422) from 0 to 100 in Fig. 6. Values of N for 60 cycles for use in equation (33) are given in Fig. 7, and of K , on the fixed condenser box. All of the constants and readings for the calculation of the characteristics of a

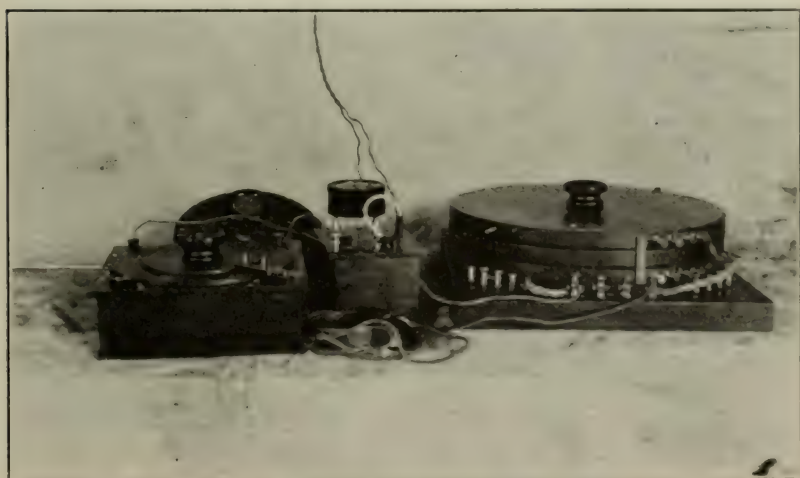
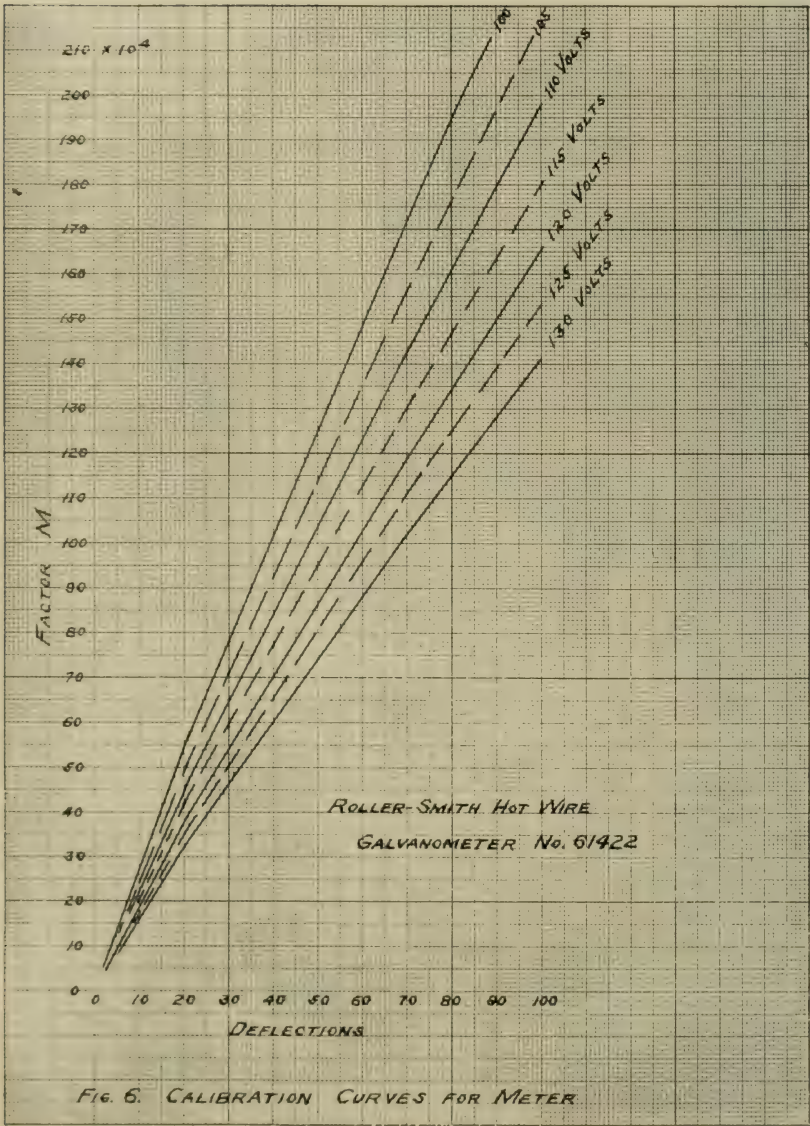
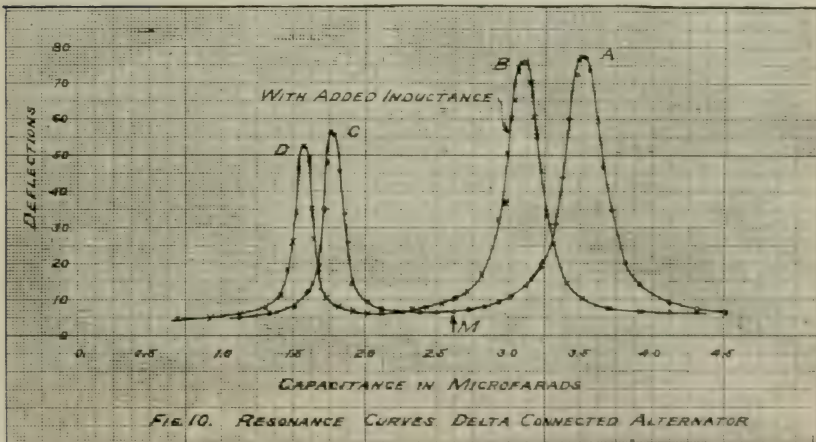
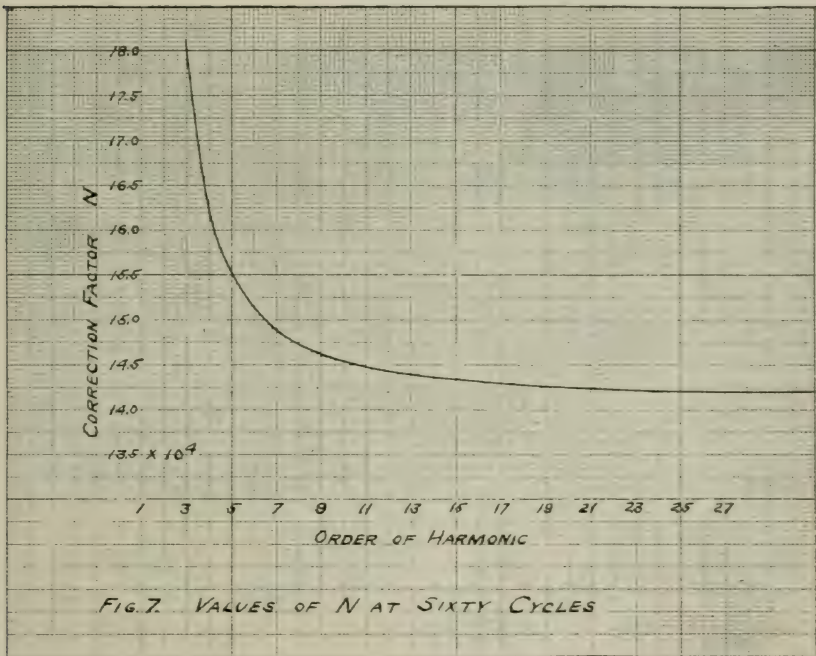


FIG. 8. HARMONIMETER WIRED FOR USE





wave may therefore be determined from the scale readings. By substitution of equation (40) in (32)

$${}_nP = \frac{0.000895 R Q_1 Q_2}{S(Q_1 - Q_2)} \quad (45)$$

EXAMPLE

A preliminary test to experimentally prove the above theory was made upon a 1200 rev. per min., 220 volts, delta-connected alternator before constructing the harmonimeter. The open circuit voltage wave at 100 volts, which was held throughout the test of this machine, is shown by oscillogram in Fig. 9. The resonance curves for this machine with and without the known inductance L taken by adjusting a standard plug condenser are shown in Fig. 10.

The inductance L , when measured separately on a 180-cycle wave gave a reactance of 12.6 ohms and therefore had an inductance of 0.0111 henry. During the test an additional inductance of unknown value was permanently connected in the circuit. C_o was 0.72 microfarad.

Maximum points A and B, in Fig. 10, corresponding to 3.53 and 3.11 microfarads, are evidently due to the same harmonic. The equation for the determination of its order is (3). Substitute and

$$n = \frac{1}{2\pi 60} \sqrt{\frac{1}{0.0111 \left(\frac{10^6}{3.11} - \frac{10^6}{3.53} \right)}}$$

from which n equals 4.9 and therefore indicates the fifth harmonic.

Maximum points C and D, at 1.78 and 1.57 microfarads in Fig. 10 are due to the presence of another harmonic. A similar solution to that above gives a value of 6.9 for n' and therefore indicates the seventh harmonic. An alternative solution is, since it is known that point A is due to the fifth harmonic,

$$n' = 5\sqrt{3.53/1.78} = 7.0$$

From these solutions it is therefore known that resonance points A and B are due to the fifth, and points C and D, to the seventh harmonic.

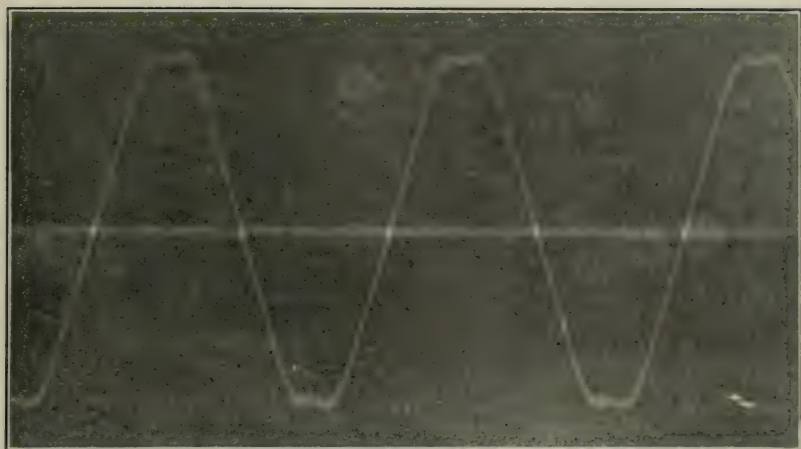


FIG. 9—OPEN CIRCUIT VOLTAGE

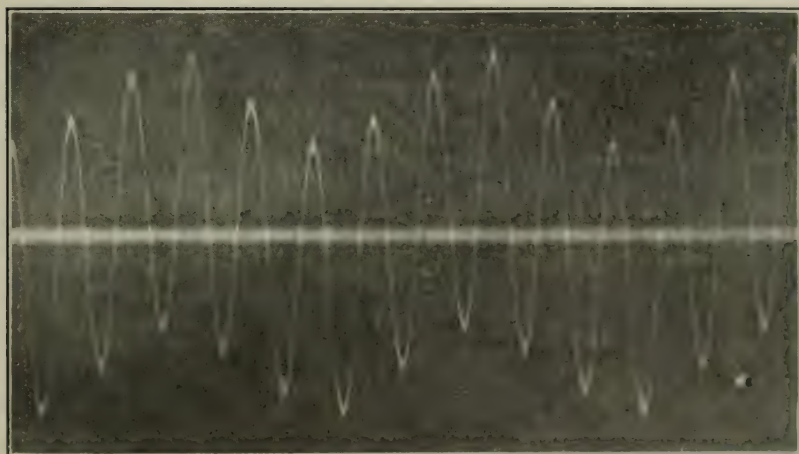


FIG. 11—CHARGING CURRENT—FIFTH HARMONIC IN RESONANCE

The readings for the determination of amplitude are given in Table VI.

TABLE VI
CRITICAL VALUES FOR PRELIMINARY TEST

Point	C	R	A_1^2	A_2^2	n	I_1	I_2	nR	nP
A	3.53	2.66	0.01214	0.00713	5	0.540	0.415	7.9	4.1
B	3.11	2.66	0.01183	0.00745	5	0.470	0.373	9.1	4.1
C	1.78	2.66	0.0091	0.0059	7	0.236	0.190	9.7	1.7
D	1.57	2.66	0.00848	0.00574	7	0.201	0.165	10.8	1.7
M	2.62	....	0.0018	.....	..	0.149	.....	...	...

Consider the conditions for point A.

From equation (4),

$$L_o \omega = \frac{10^6}{3.53 \times 5^2 \times 2\pi 60} = 30 \text{ ohms}$$

$$\frac{1}{C_2 \omega} = \frac{10^6}{3.53 \times 2\pi 60} = 749 \text{ ohms}$$

$${}_1X = 749 - 30 = 719 \text{ ohms}$$

Substitute in equation (20) and

$${}_5P^2 = {}_5R^2 \left(\frac{0.01214 \times 3.53^2}{100^2 \times 0.72^2} - \frac{1}{719^2} \right)$$

Likewise for point A', when a resistance of 2.66 ohms is placed in series, substitute in equation (21) and

$${}_5P^2 = ({}_5R + 2.66)^2 \left(\frac{0.00713 \times 3.53^2}{100^2 \times 0.72^2} - \frac{1}{719^2} \right)$$

Solve and ${}_5R$ equals 7.9 ohms and ${}_5P$ equals 4.1 per cent. Points B and B' give similar results, 9.1 ohms and 4.1 per cent.

Solving in the same way for the constants for the seventh harmonic for points C and C' and for points D and D' and ${}_7R$ equals 9.7 ohms or 10.8 ohms and ${}_7P$ equals 1.7 per cent.

Oscillograms were taken to check the above results and to show the charging current at the critical resonance points. Fig. 9 is an oscillogram of the no-load voltage of the machine and is the true generated wave form as no capacitance was connected and the resistance was at least ten times the reactance of the vibrator circuit to the seventh harmonic. An analysis of this wave gives 3.5 per cent of the fifth and 1.6 per cent of the seventh harmonic, no others being present.

Fig. 11 is the wave of charging current (0.540 ampere) for point A and shows the predominance of the fifth harmonic.

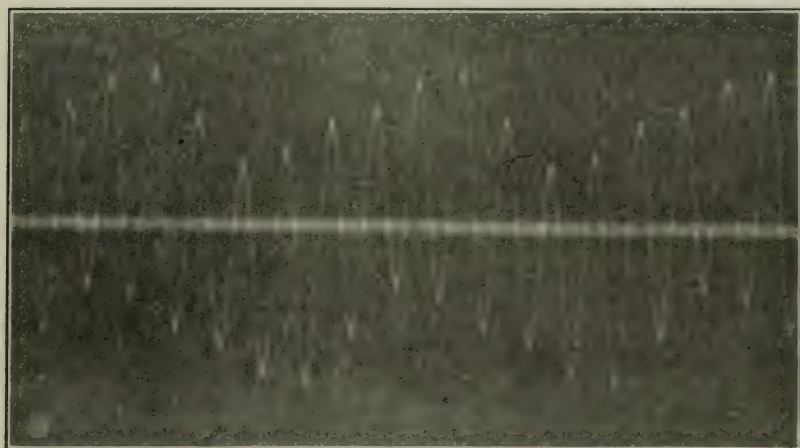


FIG.12—CHARGING CURRENT—SEVENTH HARMONIC IN RESONANCE

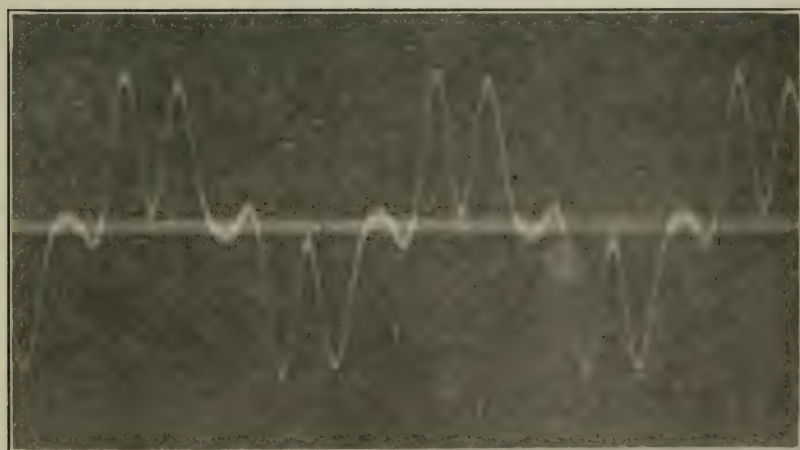


FIG.13—CHARGING CURRENT—NON-RESONANT

Fig. 12 is a similar curve of charging current (0.236 ampere) for point C showing the seventh harmonic. Fig. 13 is the wave of charging current (0.149 ampere) for point M corresponding to 2.62 microfarads in Fig. 10, showing the reduction in the amplitude of the harmonics and the beats due to both the fifth and seventh harmonics.

The resistance of the circuit used was measured with direct current and found to be 5.2 ohms for points A and C, and 6.2 ohms for points B and D. The solutions given above show that the resistance to the higher frequencies is very materially greater than to the fundamental. It is therefore necessary to solve for the resistance of the circuit from the alternating current readings or to use the equations which eliminate it.

After the construction of the harmonimeter the results for the same machine were checked as follows:—The machine was excited to give 100 volts at 60 cycles. Scale *T* of the harmonimeter was set at 35 and scale *S* at 430 which gave a maximum deflection of 100 scale divisions. On inserting a resistance of 2.58 ohms the deflection was reduced to 65 divisions. On changing scale *T* to 25, which from Table IV corresponds to a change of 0.0369 henry for reading on harmonic scale C, resonance was found for 310 on scale *S*. This gave exactly 5 on the harmonic scale C, showing that the resonance points were due to that harmonic. Values of amplitude calculated by equation (45) gave a mean value of 3.2 per cent.

TABLE VII

CRITICAL VALUES FOR TEST WITH HARMONIMETER

<i>E</i>	<i>S</i>	<i>T</i>	<i>D</i> ₁	<i>D</i> ₂	<i>R</i>	<i>n</i>	<i>nP</i>	Mean P
100	430	35	100	65	2.58	5	3.4	...
100	310	25	69	42	2.58	5	3.0	3.2
110	490	20	48	32	2.58	7	1.7	...
110	260	10	22	16	2.58	7	1.9	1.8

$$K = 1$$

$$k = 64$$

$$L = 0.0369 \text{ henry}$$

$$N = 15.5 \times 10^4 \text{ for 5th.}$$

$$N = 14.9 \times 10^4 \text{ for 7th.}$$

A summary of the above readings and those for the determination of the seventh harmonic are given in Table VII. It will be noted that the agreement of the figures for amplitude by oscillogram and from the two tests by the author's method is sufficiently close for all practical purposes. Lack of time pre-

vented the taking of a larger number of readings to obtain a better mean value.

To efficiently use the instrument requires but little practice and it is believed that the manipulator can obtain with it the harmonic components of a wave form much more rapidly than by the mathematical analysis of an oscillogram. In searching for resonant points it is well to begin with the lower harmonics. The capacitance is set near its maximum (minimum on scale S) and the variometer, connected in series, turned through its complete range. If no resonant point is found, scale S is increased and the process repeated. Further search may be made with the variometer connected in two parallel groups of four coils etc., until the entire range has been covered. A telephone receiver may be of assistance in place of the hot-wire meter for detecting weak components and works well in the 0.05 mf. tap of the fixed condenser.

When an harmonic has been found in the above manner adjustment is made for resonance and the harmonic scales manipulated to give its order. Before taking readings for its amplitude it is well to adjust for resonance with as high a value of scale S as possible as this is the condition for greatest sensitiveness. Any noninductive resistance of about one half the resistance of the remainder of the circuit will serve for R .

If the system tested be other than sixty cycles the readings on the harmonic scale should be multiplied by $60/f$ and the values of N in Fig. 7 by $(f/60)^2$. No other corrections are necessary.

SUMMARY

It is practicable to test for the order and amplitude of the harmonics in any alternating wave of voltage by the use of an inexpensive indicating meter, a known inductance and an adjustable condenser, without knowing the resistance and inductance of the machine itself. Equations are developed which permit easy solutions for these characteristics of wave shape, leaving only the phase positions undetermined.

It is shown that the most sensitive and positive indication of the presence of harmonics is made by a current indicating device in a shunt condenser circuit in parallel with an adjustable condenser. Admittance or impedance standards for wave form, with the possible exception of the telephone interference standard, are always misleading since they produce resonance by chance.

An instrument called by the author an "Harmonimeter" is described which reduces to a minimum the labor of wave analysis as developed by the equations in the first part of the paper.

An example is given of the analysis of the voltage wave form of a delta-connected, 60-cycle alternator by the author's method compared with an harmonic analysis of the oscillogram of open circuit voltage. Oscillograms and curves show the critical adjustments for resonance.

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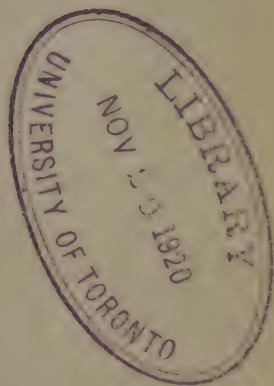
BULLETIN No. 9

The Coking Industry of the
Pacific Northwest

By

JOSEPH DANIELS

Associate Professor of Mining Engineering
and Metallurgy



SEATTLE, WASHINGTON
PUBLISHED QUARTERLY BY THE UNIVERSITY
AUGUST, 1920

THE Engineering Experiment Station of the University of Washington was established in December, 1917, in order to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is twofold:—

- (a) To investigate and to publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural and industrial affairs.
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The results of the investigations are published in the form of bulletins. Requests for copies of the bulletins and inquiries for information on engineering and industrial problems should be addressed to the Engineering Experiment Station, University of Washington, Seattle.

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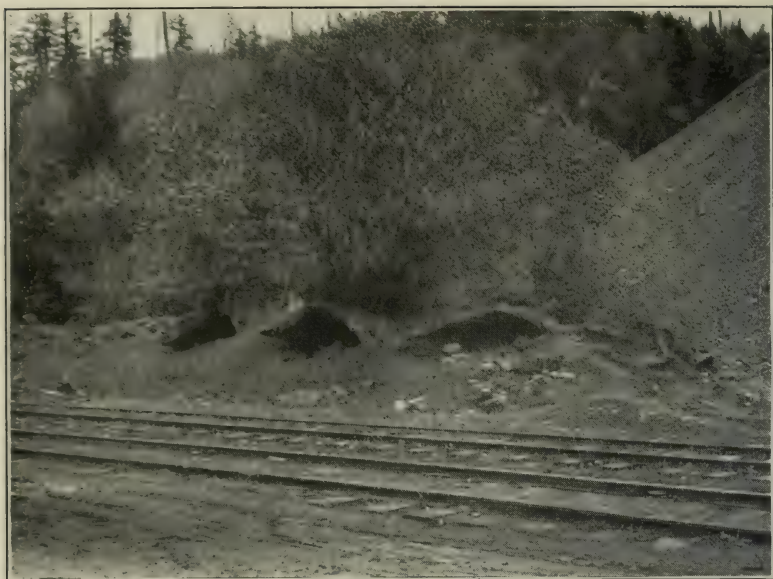
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Site of first coke ovens at Wilkeson, Washington.



First coke ovens at Wilkeson, Washington.



General view of washery and ovens, Wilkeson, Washington.



Coke ovens and tipples, Wilkeson, Washington.



Fairfax mine, washery and ovens.



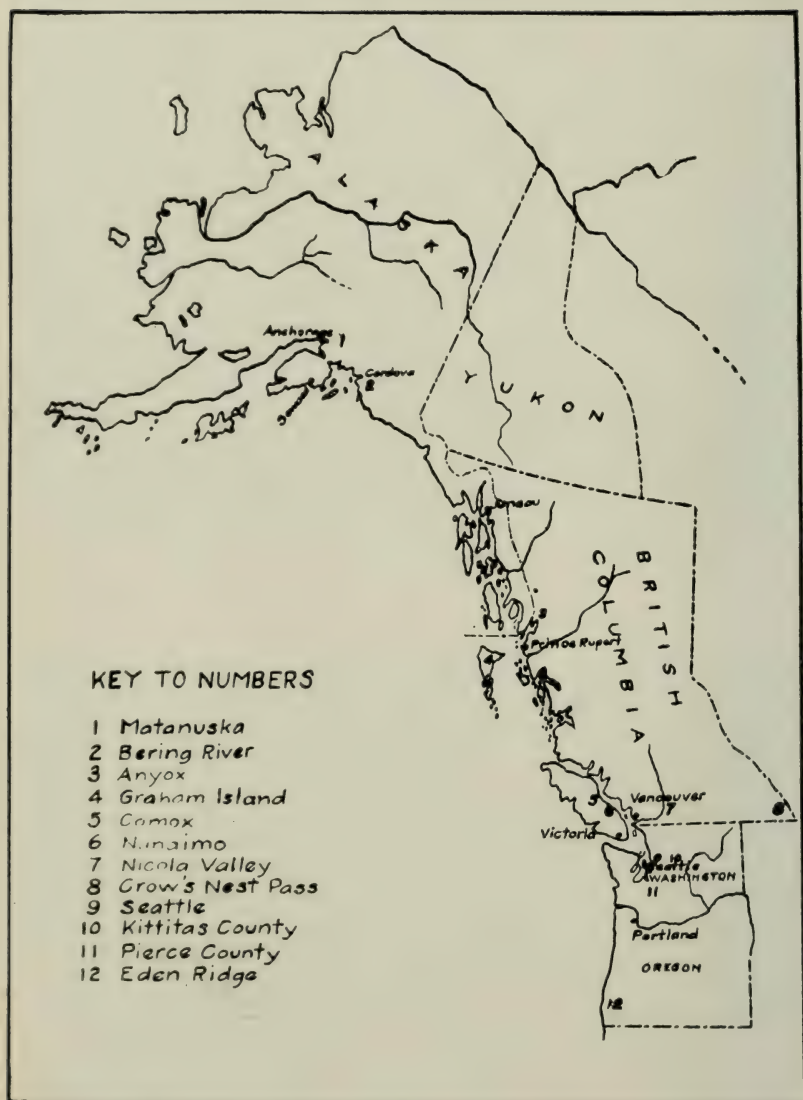
Coke oven plant at Montezuma, Washington.



Carbonado, Washington. Coke ovens under construction.



Carbonado, Washington. Coke ovens and coal bins.



Sketch Map showing Location of Coking Plants and Fields of Coking Coal on the Pacific Coast

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THE COKING INDUSTRY OF THE PACIFIC NORTHWEST

INTRODUCTION

The coking industry of Washington and British Columbia has been an important factor in the metallurgical and industrial development of the Pacific Northwest, although its magnitude has not been great. The increasing interest in the resources of this portion of North America as potential and active sources of industrial raw materials has led to considerable investigation and search for supplies of coal and coke; ores of iron, copper, lead, zinc; and many other metallic and non-metallic minerals. The question of coke has recently become prominent because of its relationship to the establishment of chemical and metallurgical plants in which this basic substance is required as a fuel or as a necessary component of the process. More particularly is this true in the present discussions of the question of establishment of iron and steel plants and associated industries in the Northwest.

Very little published information dealing with the subject as a unit is available to the ordinary investigator. Many exaggerated statements have been made, much inaccurate information has been disseminated;—opinions and beliefs, rather than scientific and technical facts have crept into the discussions of resources of coking coals, coking practice, character of product and related matters. Because of the importance of the question and the necessity for full and accurate information about the coking situation on the Pacific coast this bulletin has been prepared. The aim of the bulletin is to present the history of the industry together with the accumulated information which is scattered through articles, reports, and bulletins, supplemented by original data obtained from investigations and tests made by the writer and others. No attempt has been made to discuss the manufacture of bench coke made in gas plants. Contact with the industry has been made through frequent field trips and conferences. The results are presented in the hope that they will be of some interest and of some real value, particularly as a groundwork on which further necessary investigations may be built. Errors of statement may occur as an inevitable result of piecing together information from a wide variety of sources dealing with matters which have been passed over as insignificant and unimportant; but, in the main, the writer believes most of the data to be correct.

Acknowledgments are due and gladly given to the many members of the coal mining industry in Washington and in British Columbia who have given information and permitted the writer to study their plants, and to his associates at the University of Washington for helpful assistance and criticism in the preparation of this bulletin.

DISTRIBUTION OF COKING COALS

The exact distribution and extent of the coking coals in the areas tributary to tidewater in the Pacific Northwest are not known in detail. A resume of the distribution is here given in order to define the localities from which coke is at present produced and those which may be potential sources of supply in the future. It must be remembered that modifications in coking practice may permit some coals, now classed as uncertain, to be used in the production of commercial coke. For this reason, the following summary must be regarded as tentative and possibly incomplete. Detailed studies of the geology of the areas, information about the character of the seams, analyses of the coals, and related data may be found in the various state and national reports and bulletins.

The Pacific coast possesses extensive deposits of coal from Alaska on the north to California on the south. The maximum development of the coal mining industry is found in the Province of British Columbia, Canada, and in the State of Washington. Alaska, Oregon, and California are but small producers of coal. The resources of known coking coals within the coastal belt of the Pacific coast province are extremely limited. No coking coals are reported from California; Oregon possibly has some small resources in the Eden Ridge field; Washington and British Columbia are active producers; and some of the Alaskan coals from the Bering River and the Matanuska fields are of coking type.

In the Coast District of British Columbia the principal coking coals are found on Vancouver Island. The Cretaceous coals of the Nanaimo and the Comox districts are coking coals; both are being used in the manufacture of coke. Some of the Graham Island coal possesses coking properties. Of the coals on the mainland, closely tributary to the Coast District, no important coking areas have been developed, although it is reported that some of the seams in the Nicola Valley district have made satisfactory test coke.

The principal area of coking coal in the state of Washington is in Pierce county in the Wilkeson-Carbonado-Fairfax district. Skagit, King, and Lewis counties, on the western rim of the Cascade Range, contain coals which have been coked, but they have not proved to be as good for the purpose as the Pierce county coals. On the eastern side of the Cascades, the Roslyn field of Kittitas county contains seams which have been experimentally coked. It will be observed that the coking coals appear to be limited to a fairly narrow north-south belt lying close to the foothills of the Cascade range, a distribution which is generally believed to be due to the metamorphism of the Eocene coals, which, away from the influence of dynamic agencies, are normally free-burning bituminous and sub-bituminous in rank.

THE COKING INDUSTRY IN THE STATE OF
WASHINGTON

HISTORY

The history of coking in the state of Washington began about 1880 when pit coke was made at Wilkeson in the Pierce county coal field. The Wilkeson mines were opened in 1876, and the Tacoma Coal and Coke Company has the distinction of being the first to produce coke on the Pacific coast. The first coke was made in pits 4 feet high enclosed on the sides and ends with stone walls. The earliest reported production was in 1884 when 400 tons of pit coke were made from 700 tons of coal, giving a yield of 57.5 per cent. This coke was used in the local foundries of the state and at Portland, Oregon, commanding a price of \$4.50 to \$5.00 per ton at the ovens. The success of the coking operation in pits led to the building of two bee-hive ovens in 1885, but the entire production of that year was represented by pit coke. The building of these two ovens marks the starting point of the industry within the state. Bee-hive ovens continued to be the only type built until 1914 when 5 Klonne by-product ovens were constructed at Seattle for the Seattle Lighting Company.

Following the building of the two ovens at Wilkeson in 1885, nine more were finished in 1886 and 21 started. In 1887, thirty ovens were in operation by the Tacoma Coal & Coke Company but a slump came and in 1888 very little coke was made. Two new enterprises, however, were reported as planning the construction of 100 ovens. One of these planned to erect its ovens at Tacoma and use coal from the Wilkeson field. Tests made indicated that a coke of the following composition could be produced:

Water and volatile matter.....	2.0%
Fixed carbon	84.0
Ash	14.0

Apparently the plans were not carried out for there is no record of the construction of any new ovens until 1891, when there were two establishments at Wilkeson with 80 ovens in operation. One of these plants was that of the Wilkeson Coal & Coke Company with 50 ovens. The building of the Tacoma smelter in 1890 and the Everett smelter in 1895 may have had some influence on the development of the coking industry at this time.

In 1892 a new coal field was opened in Skagit county, near Sedro-Woolley; four ovens were placed in operation at the property of the Sedro Coal Company at Cokedale. A small quantity of coke was made that year from unwashed slack coal. An analysis of this coke, made by the Department of Mines and Mining of the World's Columbian Exposition, is given below:

Moisture	0.30%
Volatile matter	3.80
Fixed carbon	86.38
Ash	8.60
Phosphorus	0.30
Sulphur	0.62

The number of ovens at Cokedale was increased to 30 in 1895 and to 40 in 1896. An analysis of the coal and coke from Cokedale, reported at that time, is as follows:

	Coal	Coke
Moisture	0.35%	0.10%
Volatile matter	28.75	2.38
Fixed carbon	60.95	82.22
Ash	9.95	14.84
Sulphur .....	.....	0.46
	100.00	100.00

The original plant of the Tacoma Coal & Coke Company consisting of 30 ovens was abandoned in 1898. A few ruins of this establishment may be seen at Wilkeson along the railroad track leading from the present washer toward South Willis. This left in the state two plants having a total of ninety ovens.

The establishment of smelting industries on Vancouver Island gave the coke business a great impetus about 1901. In that year, Fairfax completed 58 out of its proposed plant of 60 ovens, making three establishments with 148 ovens, and Montezuma began the construction of 25 ovens. In 1902, there were five establishments and 231 ovens. Of this number, 50 represented an addition to the Wilkeson plant, giving it a total of 100 ovens, the largest battery in the state; 25 comprised the installation at Montezuma; two the completed battery at Fairfax; and six an experimental battery at Carbonado. The experimental operations in coking at the latter place were not satisfactory and the project was abandoned.

In 1903, 25 ovens were built at South Willis, but these produced only 1700 tons. The total number of ovens in the state then amounted to 256 and the number of establishments was six. In 1905, the Cokedale establishment was abandoned; some of the coke from this plant was used at the iron blast furnace at Irondale but apparently was not as desirable as charcoal, which was the fuel substituted for coke. The elimination of this plant, together with the idle battery at Carbonado, left four establishments with a total of 210 ovens. Of these only 185 were active, as the South Willis plant produced little coke.

A battery of 50 ovens was planned at Snoqualmie in 1908 but of these only 12 appear to have been completed and practically no coke was made. The status of the industry remained constant until 1912 when Carbonado completed fifty ovens, of which six represented the experimental battery erected in 1902. Twenty-one ovens were added to this plant in 1913 making a total of 71 ovens for the Carbon Hill Coal Company. The total number of ovens in the state, excluding Snoqualmie, was 281 and the number of establishments five.

No more bee-hive ovens were built until 1917 when the Wilkeson Coal & Coke Company added 60 ovens to its establishment. This installation did not operate properly owing to the failure of the brick used in its construction and the plant was temporarily closed until 1918. About the same time, 1917, the Carbon Hill Coal Company began the construction of 66 additional ovens, but on account of the limited space available at Carbonado, the new plant was located at Crocker near Orting, the junction of the mine branch with the Buckley branch of the Northern Pacific railway. Thus without increasing the number of establishments the total number of bee-hive ovens in the state at the close of 1918 had risen to 419.

The industrial activity which followed the opening of the great war created an enormous demand for coke on the Pacific Coast. The ovens at South Willis which had been idle for several years were re-opened by the Wilkeson Coal & Coke Company in July, 1915, and were used in producing coke from coal mined at Wilkeson. The opening of the smelter of the Granby Consolidated Mining, Smelting & Power Company at Anyox, British Columbia, in 1914 also increased the market for Pierce county coke and this undoubtedly was an influencing factor in the building of the new ovens in the state during 1917. With the exception of the ovens at Montezuma all the ovens in the state have been in use since 1916. In 1918 there were some reports of a proposed rebuilding of the coke ovens at Cokedale. During 1919, the ovens at Crocker were leased to the M. S. Allison Company, Inc. The Western Coke & Collieries Company were rebuilding the battery of fifty ovens at Snoqualmie, which were put into active service in April 1920, coke shipments beginning shortly afterwards. During 1920 the rehabilitation of the old ovens of the Cokedale Coal Company was begun. Thirty-five of the old battery of forty ovens are, according to report, to be rebuilt and coke production started as soon as possible.

The following table summarizes the bee-hive coke oven plants in Washington at the close of 1919.

COMPANY	LOCATION	NUMBER OF OVENS
Wilkeson Coal & Coke Co.....	Wilkeson	160
Wilkeson Coal & Coke Co.....	South Willis	25
Carbon Hill Coal Co.....	Carbonado	71
Carbon Hill Coal Co.....	Crocker	66*
Fairfax Mine, Inc.....	Fairfax	60
Wash. Manganese Coal & Copper Co..	Montezuma	25
Western Coke & Collieries Co.....	Snoqualmie	50
		457

*Leased to M. S. Allison Company, Inc.

In 1914 the Seattle Lighting Company constructed at its plant on Lake Union a battery of 5 by-product ovens of the Klonne type made by the National Chamber Oven Company consisting of 20 chambers

(four to an oven), each 27 feet long by 17 feet high by 13 inches by 18 inches wide. These were primarily erected for gas manufacture and the coke produced was at first largely sold for domestic use. However, the shortage of coke on the coast led to the use of this coke for metallurgical purposes, and with certain modifications in the coking practice the product was made suitable for copper smelting and, to a limited extent, for foundry purposes. Up to the time of the building of the plant at Anyox, this was the only installation of by-product ovens on the coast.

COKING PRACTICE

The coal used in the bee-hive ovens usually comes from the local mines adjacent to the ovens. Only one plant, so far as is known, has purchased outside coal from a distant mine for its supply. The coal used from 1891 to 1895 was mainly washed slack; in 1896 more than half was washed run-of-mine; in 1897 all of the coke was made from washed run-of-mine. Since 1890, therefore, practically all of the coke has been made from washed coal, and it appears that in Washington washed coal alone is the only material that can be used if the ash content of the resulting coke is to be kept at a reasonably low figure. Some raw coal from Kittitas county has been used in the bench gas plant at Seattle, but, in the main, the washed fine sizes constitute the supply for both the bee-hive and the by-product ovens. In general, the coal is prepared by screening followed by jigging. In some plants concentrating tables have been introduced to handle the sizes too small for proper treatment in jigs. Washington coals are normally high in ash and it is difficult and expensive to produce extremely low ash coal for coking. In recent years there has been a noticeable increase in the ash content of marketed coals and coke. This may be due to a natural falling off in the quality of the seams being mined or it may be due to poorer preparation:—probably both factors have contributed to lowering the quality of the product. In any event, the fact remains that the high ash content of local coke is a detriment and that improvement in the quality of the coal used is necessary if the coke industry is to serve as a foundation on which to build other industries. It is believed that more careful selection of coking seams and more attention to the problems of washing will overcome part of the natural handicaps of high ash coal.

The Seattle station of the United States Bureau of Mines and the College of Mines of the University of Washington are now engaged in cooperative work with the mining industry in an effort to improve the quality of washed coal through careful studies of the specific gravity of coal by float and sink tests, determination of the nature of the ash, experimental work in concentration of coals, and finally by direct operation of typical washing plants in each locality. These investigations promise to lead to a lowering of the ash content, particularly in the coals suitable for metallurgical use.

The bee-hive ovens employed in the state are of the usual type and show no special features in design or construction. Some mechanical chargers and unloaders are used, but hand methods are the rule. The product made is 48 and 72-hour coke although some 96-hour coke is made for special use. The 48-hour coke is generally sold to copper and lead smelters, and the 72 and 96-hour material is sold to foundries and industrial plants. The charges vary from 10,000 pounds for 48-hour coke to 14,000 pounds for 72-hour coke, and the yields vary between sixty and sixty-five per cent. The by-product plant at Seattle uses 13,000 pound charges and a coking period of twenty-four hours.

ANALYSES OF COKE

Typical analyses of Washington coke are difficult to give because of the varying product from each plant under differing conditions. However, a few analyses are given below:

	Moisture at 105° C.	Volatile matter	Fixed carbon	Ash
Wilkeson	0.76%	1.99%	79.58%	18.67%
	0.72	2.81	78.20	18.27
	0.70	1.26	77.70	20.34
	0.78	1.53	77.71	20.98
Carbonado	1.12	2.81	79.21	16.86
	0.55	1.25	78.44	19.76
Fairfax	0.52	1.25	79.49	18.74
	0.07	1.04	80.49	18.40
	0.18	1.35	79.47	19.00
	0.09	1.01	80.49	18.41

Belden in Technical Paper 50, United States Bureau of Mines, 1913, gives the following as an average analysis of Washington bee-hive coke:

Moisture	0.92%
Volatile matter	1.50
Fixed carbon	79.58
Ash	18.00
Sulphur	0.52

A few analyses of by-product coke from the Seattle plant are given for comparison.

Moisture at 105° C.	Volatile matter	Fixed carbon	Ash
0.39%	0.63%	80.50%	18.48%
0.40	1.00	80.00	18.60
0.25	1.45	78.40	19.90
0.10	3.58	77.61	18.71

The results of an experimental test in a by-product oven on Carbonado coal coked for 24 hours gave the following:

Volatile matter	3.70%
Fixed carbon	77.60
Ash	18.70
Sulphur	0.65
Phosphorus	0.11

Coke made in experimental tests by the Bureau of Mines* in 1908 and 1909 from Roslyn and Carbonado coals yielded the following analyses:

	Roslyn a	Carbonado b
Moisture	2.40%	0.03%
Volatile matter	1.83	0.71
Fixed carbon	79.45	80.99
Ash	16.32	18.27
Sulphur	0.57	0.44
Phosphorus	0.12	0.048

a—51-hour test on washed, finely crushed coal.

b—44-hour test on washed, finely crushed coal.

As already pointed out, the ash content of the coke made during the last few years has been steadily increasing and the foregoing analyses represent minimum ash. Usually the Pierce county cokes have a moisture content up to one or two percent, volatile matter up to four per cent, minimum ash from eighteen to twenty per cent, fixed carbon making up the balance. Sulphur is usually low, less than one per cent, and phosphorus is believed to be within the limits for ferrous metallurgy. All the coke is suitable for non-ferrous metallurgy, and the 72 and 96-hour coke is believed to be structurally satisfactory for iron smelting purposes in the blast furnace.

The Denver tests, already referred to, included data on the physical properties of the resulting coke. This data is tabulated below:

	Carbonado	Roslyn
Specific Gravity		
Apparent	1.03—1.10	0.89—0.96
Real	1.97—1.99	1.89—1.94
Volume		
Coke—per cent	53.00—55.00	47.00—50.00
Cells—per cent	47.00—45.00	53.00—50.00
Weight per Cubic Foot		
Wet—pounds	92.54—96.55	87.25—91.48
Dry—pounds	63.25—68.47	54.18—60.08

A few samples of Seattle by-product coke examined by the writer gave the following physical values:

True specific gravity	1.97
Apparent specific gravity	1.05
Percentage of coke substance by volume.....	53.40
Percentage of cell space by volume.....	46.60

Tests made at the University of Washington to determine the strength of this coke from the local by-product ovens gave unit crushing strength varying from 564 to 1260 pounds per square inch on small cubes and prisms in compression. A cross-bending test on a piece 1.85" x 1.97" x 7" long, supported on a span of 6.22", failed at 150 pounds pressure. These results indicate that the usual coke made here is strong enough to support the burden of a blast furnace. So far as is known, no tests

*Bulletin 5, United States Bureau of Mines. Washington and coking tests of coal at the fuel-testing plant, Denver, Colorado, July 1, 1908 to June 30, 1909. By A. W. Beiden and others.

have been made on Washington coke to determine its resistance to solution by CO_2 gas. Although not of immediate practical importance, this matter might need technical investigation in the event of the establishment of iron blast furnaces on the Pacific coast. It is believed, however, that the bee-hive coke will meet all the requirements of a blast furnace fuel.

The Seattle Lighting Company has carried on experiments in its by-product ovens using many coals from the Northwest and has accumulated much valuable data regarding their coking qualities, yields, by-products, and the like. This information has not been available for general publication.

MARKETS

The market for Washington coke extends from California to Alaska. The smelters at Tacoma and at Anyox, have in the past taken the bulk of the production, with lesser quantities going to the California smelters. Local foundries, shipyards, and industrial plants supply a market for the better grades. The domestic market absorbs a small quantity of by-product coke for household use, but the bulk of this trade is supplied by bench coke. The loss of the British Columbia market due to the establishment of the by-product plant of the Granby Company at Anyox will have a marked effect on the production until new markets become available. Actual development of electro-metallurgical and electro-chemical establishments in the coast district will call for increased quantities of coke, but it is believed that the existing plants can meet all the demands for many years.

In the eastern part of the state the coke market in normal times is subject to competition from Canadian coke from the Crow's Nest Pass district. Some of this coke also enters the Puget Sound markets. Utah coke has not entered the markets of Washington to a great extent, but it is sold in Oregon and California and may be regarded as a possible competitor in view of the market already created for Utah coal. A small quantity of high grade eastern coke is shipped to the local market for special use.

Very little foreign coke has entered the local ports for many years nor is it believed that any of this material will ordinarily find its way into the Pacific Northwest. On the other hand the export trade in coke, with the exception of the recent trade with British Columbia, has been practically negligible and it is unlikely that the high ash coke of the state will be able to create a foreign market.

PRODUCTION STATISTICS

Statistics of production, yield, and prices are given in Table I and the accompanying chart. From them it will be seen that Washington has produced 1,509,672 short tons of coke valued at \$8,821,060.00 at

the ovens. In the figures giving total coke production no account is taken of breeze, or small sizes, produced. Since 1914 the figures include the yield of by-product coke; before that date, with the exception of 1884 and 1885, the productions quoted are for bee-hive coke alone. The table has been compiled principally from statistics gathered by the United States Geological Survey and published in the volumes of Mineral Resources of the United States. Several discrepancies occur in reported statistics since the beginning of the by-product production, and in order that the record may be clear a table of by-product production, Table II, is included.

The production of by-product coke has been 147,373 tons, all of which has come from the Lake Union plant of the Seattle Lighting Company. The remaining coke production, 1,362,373 tons, represents bee-hive coke, practically all of which came from Pierce county.

The average yield of all coke has been fairly constant, remaining in the vicinity of 60 per cent. By-product coke shows a slightly higher yield, especially if the production of breeze is taken into account. Prices have been steadily rising since 1915 and the average price per ton is higher than in most of the producing states of the country. This has been due to the fact that coal mining costs have primarily been greater in Washington for many years than in other mining states. Added to this has been the cost of preparation and the cost of coking, all of which have felt the effect of the advanced wage-scales. It appears that the cost of producing coke will always be higher than in the more favored localities in other parts of the country.

Chart showing Coke Production of Washington and British Columbia

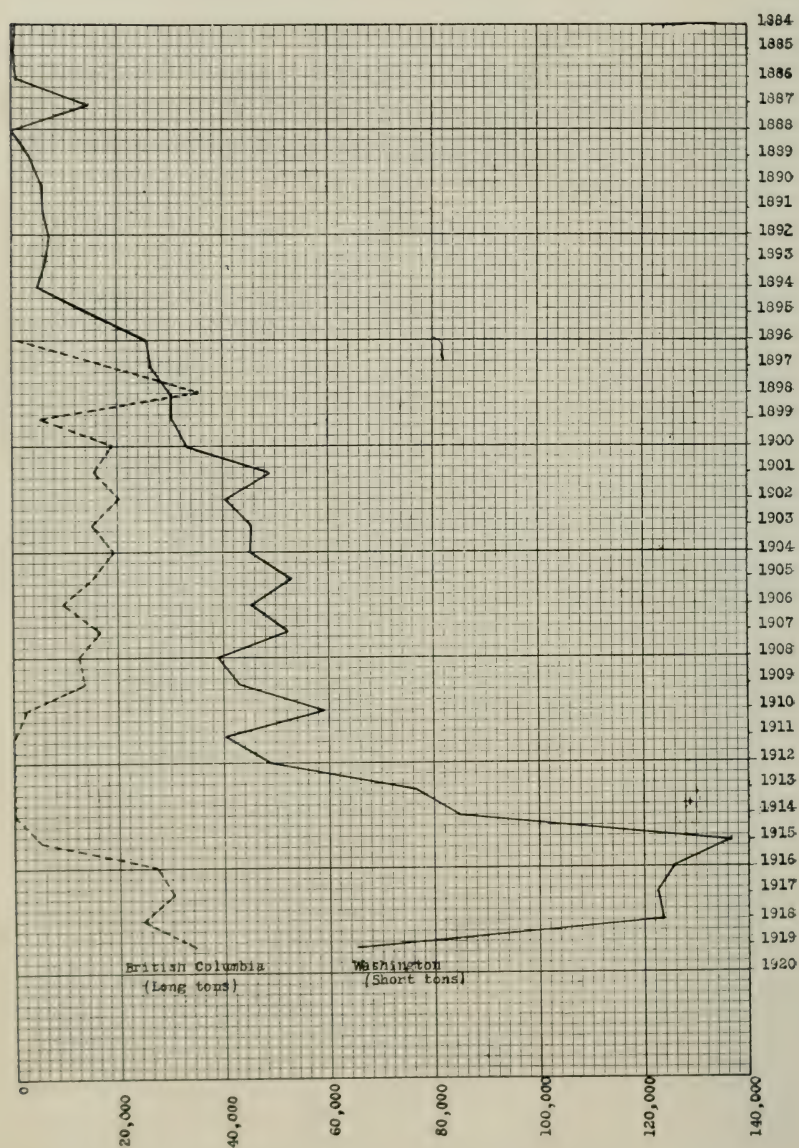


TABLE I

STATISTICS OF MANUFACTURE OF COKE IN WASHINGTON 1884-1919

Year	Coke Produced (Short tons)	Total Value of Coke at Ovens	Value of Coke at Ovens per ton	Yield of Coal in Coke (%)
1884	400	\$1,900	\$4.75	57.5
1885	311	1,477	4.75	57.0
1886	825	4,125	5.00	58.9
1887	14,625	102,375	7.00	65.0
1888	0	0	0	0
1889	3,841	30,728	8.00	55.0
1890	5,837	46,696	8.00	64.0
1891	6,000	42,000	7.00	60.0
1892	7,177	50,446	7.03	58.0
1893	6,731	34,207	5.08	59.0
1894	5,245	18,249	3.48	61.2
1895	15,129	64,632	4.27	65.9
1896	25,949	104,894	4.04	67.0
1897	26,189	115,754	4.42	67.0
1898	30,197	128,933	4.27	62.2
1899	30,372	151,216	4.98	59.8
1900	33,387	160,165	4.80	61.5
1901	49,197	259,028	4.86	62.7
1902	40,305	199,195	4.94	58.8
1903	45,623	214,776	4.71	62.4
1904	45,432	207,357	4.56	59.0
1905	53,137	251,717	4.74	62.0
1906	45,642	226,977	4.99	59.4
1907	52,028	293,019	5.63	60.6
1908	38,889	213,138	5.48	57.1
1909	42,981	240,604	5.60	61.7
1910	59,337	347,540	5.86	63.0
1911	40,180	216,262	5.38	66.6
1912	49,260	279,105	5.67	62.6
1913	76,221	432,770	5.68	64.2
1914	84,923a	472,531	5.56	63.7
1915	136,552a	700,832	5.13	66.7
1916	125,872a	662,987	5.27	61.3
1917	122,758a	906,318	7.38	59.7
1918	123,788a	1,092,741	8.81	60.6
1919	65,332a	565,356	8.65	63.4
	1,509,672	\$8,821,060		

a—Includes by-product coke

TABLE II
PRODUCTION OF BY-PRODUCT COKE IN WASHINGTON 1914-1919*

Year	Coke Produced (Short tons)	Breeze Produced (Short tons)	Total Coke Produced	Yield of Coal In Coke (%)	Yield of Coal In Breeze (%)	Total Yield (%)	Value of Coke	Value of Breeze	Total Value
1914	6,751	441	7,192	66.80	4.37	71.17	\$ 36,858.66	\$ 441.38	\$ 37,300.04
1915	30,182	4,142	34,324	65.07	8.90	73.97	158,472.17	4,120.81	162,592.98
1916	29,516	3,959	33,475	64.51	8.65	73.16	159,321.69	3,984.46	163,306.15
1917	27,635	3,889	31,524	61.38	8.64	70.02	210,857.81	4,160.90	215,018.71
1918	26,260	3,959	30,219	61.83	9.32	71.15	233,815.01	3,958.42	237,773.43
1919	26,955	3,959	30,914	61.14	8.98	70.12	207,116.23	3,967.01	211,083.24
	147,299	20,349	167,648				\$1,006,441.57	\$20,632.98	\$1,027,074.55

*Figures furnished by Seattle Lighting Co.

The general increase in all commodity prices since the war has also had an influence in increasing the average price at the ovens. The future tendency appears to lie in sustained prices although a slight drop may develop because of the loss of former metallurgical markets and the general curtailment of non-metallurgical industries using coke. Bee-hive coke production can be made to respond very readily to the market demands and for this reason there will probably never be sufficient overproduction in the state to depress prices materially.

Pierce county holds the lead in coke production of the state as it does for the Pacific coast. In this field the Wilkeson ovens have been steady producers, first with two ovens in 1885, 11 in 1886, 30 in 1887, 80 in 1891, 50 in 1898, and 160 in 1918. The ovens at Fairfax, 60 in number, have been regular producers since 1901. Carbonado, with 137 ovens, has been an important factor since 1912, the year it first produced coke. The Montezuma and the South Willis plants of 25 ovens each have been intermittent producers. The Skagit county production at Cokedale was not large but it represented an active phase of the industry during the years 1892 to 1905. The revival of the Snoqualmie plant in King county is a new development which will be watched with considerable interest.

The establishment of the by-product plant in Seattle in 1914 marked a distinct forward step in practice, but as the plant has been operated primarily for the production of illuminating gas, the by-product coke may be regarded as a secondary product. However, this plant is necessarily a steady producer of coke and it must be regarded as an important factor in meeting fluctuating market demands, although its product is not normally regarded as metallurgical coke.

SUMMARY AND CONCLUSIONS

Washington possesses areas of coal suitable for the manufacture of bee-hive or by-product coke. The coal is principally distributed along a north-south belt extending along the west slope of the foothills of the Cascade range from Skagit county on the north to Lewis county on the south. A secondary field lies along the east side of the Cascades in Kittitas county. Active coking operations are confined to King and Pierce counties, although Skagit county has been a producer. The coal is not of uniform quality and full scale testing must be undertaken before final conclusions can be reached regarding the properties of the various beds. The coals are mainly high in ash, consequently high ash

coke must be expected as the general product, although investigations now being carried on may result in an improvement in the quality of the washed coal used in the manufacture of coke.

The total number of bee-hive ovens in the state is 457 in seven establishments. The by-product plant at Seattle consists of five ovens containing 20 chambers. The usual practice is to make 48-hour coke in the bee-hive ovens for ordinary metallurgical use, and 72 to 96-hour coke for special and foundry purposes. The by-product coke is a 24-hour product.

The average product made in the state contains moisture and volatile matter in amount less than four per cent each, and ash ranging from eighteen per cent upward. Sulphur and phosphorus are low. The crushing strength of some test pieces of average by-product coke ranged from 500 to over 1,000 pounds per square inch. Recognizing the inherent limitations of high ash, the coke appears to meet all the requirements of a fuel for metallurgical industries, ferrous and non-ferrous, and for general industrial use.

The past production has been ample to meet the demands of the various metallurgical industries, foundries, and industrial plants of the northwest. It is estimated that the ovens now built can produce a minimum of 150,000 tons of coke annually under continuous operation. The largest production, 136,552 tons, in 1915, was obtained from 382 bee-hive ovens and 20 by-product chambers.

The proximity of most of the ovens to tidewater shipping points enables the coke to enter any Pacific coast market. In the past the market has extended from California to Alaska. The ash content and the price of the coke will ordinarily not permit it to develop a market far from the domestic demand close to the coast, but it should fill an important place in local development. The influence of British Columbia competition must be borne in mind, as well as the possibilities of development of Alaska's coals, but these are regarded as secondary in view of the present development and strategic importance of the industry in Washington.

THE COKING INDUSTRY IN THE COAST DISTRICT OF BRITISH COLUMBIA

HISTORY

Coke has been produced on Vancouver Island at Union Bay in the Comox district since 1896 and 1897. The coal at the Union Collieries was early known to be of the coking variety and in 1895 a contract was let for the construction of 100 ovens. Brick and blocks were imported in the early part of 1896 for a battery of 100 ovens. The ovens were of the bee-hive type, but equipped with flues to conduct the gases to a heating plant which supplied power for the washer and oven equipment. Economic considerations were important factors in the establishment of this plant. California at this time was importing 75 per cent of its metallurgical coke from England and Belgium. It appeared that cheap water transportation from Union Bay to the California market would enable the British Columbia product to compete with the European coke. The Kootenay smelters in eastern British Columbia were also possible markets, particularly as the railroads promised special freight rates from Vancouver, and plans were considered for loading cars on barges to be transferred to Vancouver from Comox without rehandling of the coke.

The first ovens built, which did not come up to expectations, were taken down and rebuilt during 1897. The fire brick and blocks used in the new construction were made from fire clay mined in the Union Colliery. The rebuilt ovens worked satisfactorily and the 1897 production of 17,831.5 tons found a ready sale both in British Columbia at the Kootenay smelters and in California. The construction of an additional battery of 100 ovens was projected. In 1898 these were completed, making a total of 200 ovens in the plant. The analysis of the coke made at this time was reported to be:

Moisture	0.60%
Volatile matter	2.60
Fixed carbon	80.00
Ash	16.80

The production of coke continued at a fluctuating rate varying with market conditions. The local trade was small in quantity but the amount sold in the United States increased until 1901 and 1902. In that year only 70 ovens were producing, but the blowing-in of the smelter of the Tye Copper Company at Ladysmith created a new demand which, in 1903, caused the entire production to be used at home. The California market, which had been the principal American outlet for Comox coke since 1897, received no coke in 1903. During the next few years the export shipments to California grew smaller and ceased entirely in 1905 or 1906. The loss of the California market was probably due to the failure to ship coke in 1903; this had a marked effect on the production of coke in the state of Washington and may account for the increased activity of the Puget Sound coke ovens because of the acquisition of the southern market.

The Crofton smelter of the Northwestern Smelting and Refining Company was completed at this time, but it was not regularly operated until 1906. In 1905 two smelting plants on Prince of Wales Island were blown in. These plants drew their coke from Vancouver Island until they were shut down in 1909, and the exports from Comox during these years were entirely to the Alaskan market. About this time, 1905, the local demand for coke on Vancouver Island dropped because of decreased copper smelting, but the market improved in 1906.

The spring of 1907 witnessed the unusual occurrence of a Vancouver Island smelter, the Crofton, importing coke from Australia to the amount of 3,000 tons, and an Alaskan smelter forced to shut down temporarily for the lack of British Columbia coke, the exports of this year being only 220 tons. The fact that the producing company found it more profitable to sell coal during that year than to make coke explains the situation. Why Washington coke was not used is a puzzling question but it may be inferred that commercial rivalry was the reason. That the Washington industry was benefited is shown by the fact that practically all the ovens in Washington were operated that year and that the average value of the coke at the ovens in Washington increased from \$4.99 in 1906 to \$5.63 in 1907. This period of activity was followed by a depression because of a falling off in the production of the Tyee smelter and also because the smelters on Prince of Wales Island were shut down in 1909, cutting off the entire export trade of British Columbia. The Crofton smelter was not in operation after 1908 and the Tyee smelter practically ceased operations in 1911.

The production of coke ceased in 1910 with the loss of the domestic market due to the complete cessation of operations of the Vancouver Island smelters, the loss of the export trade, and the high freight rates to the interior markets of British Columbia. The fact that it was more profitable at times to sell coal directly instead of making it into coke probably had some influence in curtailing production. In 1910, the Comox Collieries, formerly operated by the Wellington Colliery Company were taken over by the Canadian Collieries (Dunsmuir) Limited. Stocks of coke on hand were gradually reduced until 1914, when the sales exhausted the supply.

In March, 1914, the Granby smelter at Anyox, British Columbia, was blown in. The immediate effect of this was of great importance to the coke industry of the Pacific Northwest, but more particularly to that of Vancouver Island, for it created a new and important market. In 1915, 100 coke ovens at Union Bay were put into service and produced 5450 tons of coke, 5383 tons of which were shipped to Anyox. The average price of this coke was between \$6.00 and \$7.00.

In 1916 the production of coke took a decided jump. Most of this coke was sold to the Anyox smelter and none was exported to the United States. In 1917 a new battery of 100 ovens was built to replace one of the former units which had been abandoned, again bringing the total number of ovens up to 200. These ovens produced some coke, but the

extraordinary demand for coal resulted in a lessened coke production and the ovens were not used to capacity.

During 1918, the Granby Consolidated Mining, Smelting and Power Company acquired coal properties in the Nanaimo district of Vancouver Island near Cassidy and a mine was opened on the Douglas seam to supply coal for a battery of by-product ovens then under construction at Anyox. These ovens began to produce coke during the summer of 1919. The immediate effect was to curtail the production of bee-hive coke at Union Bay by the Canadian Collieries (Dunsmuir) Limited, and to depress production in the State of Washington. The construction and operation of the ovens at Anyox marks an important step in the history of coking on the Pacific Coast. This is the first by-product plant on the Pacific Coast operated primarily for the direct production of metallurgical coke especially as a unit of a copper smelting plant.

COKING PRACTICE

The bee-hive coke produced at Union Bay on Vancouver Island is made from coal mined in the Cumberland district at the properties of the Canadian Collieries (Dunsmuir) Limited. A railway twenty-two miles long connects the mines with the washery, coke ovens, and shipping facilities at Union Bay. Transportation from this point is over the line of the Esquimalt & Nanaimo Railway on Vancouver Island, or by water to coast points. The mined coal is usually screened at the tipples, the sizes coarser than $1\frac{1}{4}$ " being shipped as commercial coal. The fine sizes are sent to the washery at Union Bay for preparation. The method of preparation is as follows: The raw coal is given a preliminary treatment in a Jeffrey-Robinson cone washer; the overflow passes to shakers where it is separated into nut and pea sizes, which are ordinarily shipped to market, and into sludge, through $\frac{3}{8}$ " round openings, which goes to concentrating tables for final washing. Part of the refuse from the cone washer is crushed and screened and then delivered to concentrating tables. All of the cleaned coal from the tables, which are of the Massco type, is sent to the washed coal bins from which it is delivered to the coke ovens.

The ovens are of the usual bee-hive type. The usual charge of coal is six and one-half tons; the coking period is normally 72 hours. A small quantity of 72-hour coke has been made from specially washed coal for foundry use by the company, but the principal bulk of the product has been smelter coke for non-ferrous use.

The by-product plant of the Granby Consolidated Mining, Smelting and Power Company is situated at Anyox, B. C. The installation consists of a battery of thirty ovens, each $37'-10'' \times 9'-10'' \times 18'' \times 21''$ made by the Gas and Coke Company of America. The charge of coal is thirteen tons per oven, coking period 18 to 24 hours; daily capacity of battery 270 tons. The gases and tars are conducted to coolers.

separators, extractors, and stills, making, in addition to the coke, the following products: gas, tar, ammonium sulphate, benzol, toluol, solvent naphtha, and naphthalene. The coal used at the Anyox plant is obtained from the company mine opened on the Douglas seam at Cassidy in the Nanaimo district of Vancouver Island. The mined coal is screened and washed in jigs made by the Roberts and Schafer Company of Chicago. The coarse sizes, such as lump, nut, and pea, are sold and the fine washed slack is shipped to Anyox by barge.

Experimental coking tests of British Columbia coals have been conducted by the Mines Branch of the Canada Department of Mines. These are fully described in "An Investigation of the Coals of Canada with Reference to their Economic Qualities," by J. B. Porter and others, Vol. 1, 1912. Private tests have also been made of many of the coals of the Coast District; all of the data of these tests is not available but a few summaries are given.

Some of the Nicola Valley coals have been coked experimentally yielding a fair coke. This test coke does not have the structure of the Comox coke and it would not ordinarily be suitable for metallurgical coke. However, careful selection of seams and testing of large quantities of coal under actual operating conditions are necessary before final conclusions can be reached.

The Graham Island deposits have been investigated as possible sources of coking coal. The results of preliminary testing are not final. They indicate that some of the seams in the vicinity of Camp Wilson can be coked, but the character of the test coke made in the laboratory is not entirely satisfactory from a physical standpoint. Just as in the case of border-line coals from other places, the laboratory tests alone do not give positive results. They must be regarded as indicative rather than as final and must be followed by full-scale operation tests.

Two analyses of Comox coke are given below together with data on physical properties:

Moisture at 105° C	Volatile matter	Fixed carbon	Ash	Sulphur	Phosphorus
0.60%	4.79%	76.54%	18.07%	0.85%	0.054%
0.30	2.65	73.00	24.05	0.66	0.048
	Apparent specific gravity	True specific gravity		Per cent cell space	
	1.03	1.93		47.2	
	1.13	1.95		42.0	

The first analysis is from a sample of 72-hour foundry coke, the second is 72-hour smelter coke.

A sample of Anyox coke recently analysed in the laboratories of the College of Mines gave the following data:

Moisture	0.38%
Volatile matter	4.80
Fixed carbon	69.12
Ash	25.70
Apparent specific gravity	1.00
True specific gravity	1.87
Per cent coke substance	53.4
Per cent cell space	46.6

The sample does not represent more than fair coke and is not comparable in structure or analysis with the coke produced in other plants on the coast. No information is at hand about the coal or coals used in making this sample, nor is one sample to be taken as representative of the entire product. The information at hand, however, indicates that the Douglas seam coal alone does not make high grade coke in the by-product ovens at Anyox and that considerable modification in practice is necessary to produce a first quality coke suitable for all metallurgical purposes.

J. D. MacKenzie* reports the following analysis of test coke made from No. 1 opening at Camp Wilson, Graham Island:

Total moisture	2.3%
Volatile matter	6.1
Fixed carbon	74.1
Ash	17.5

He reports that the coking qualities appear to be excellent, judging from tests made with small quantities of pulverized coal which were coked in a coal fire. Tests made at the College of Mines also indicate that the coking qualities of the Wilson seam are good.

MARKETS AND PRODUCTION

The market field for British Columbia coke has in the past coincided with that of Washington. During the years 1897 to 1902, California took the bulk of the Comox production; following this period, until 1910, the local smelters in British Columbia absorbed the supply, a small quantity entering Alaska. No exports have been made to the United States since 1910, all the recent production having been consumed at home. The United States and Canada have reciprocal relations in the coke trade, neither country imposing a duty on coke imported from the other. This means that the Pacific Coast coke has no customs differential acting against Washington or British Columbia.

As in the State of Washington, coke made on the coast does not normally enter the eastern British Columbia market. The high freight rate and the superior quality of Crow's Nest Pass coke prevent competition. The total production of coke in the Coast District to the close of 1919, Table III, has been 342,179.5 long tons of coke. Of this, 19,206 long tons represents the production of by-product coke at Anyox during 1919. A graph showing the comparative productions of British Columbia and Washington by years is shown on page 18.

SUMMARY AND CONCLUSION

The only development of the bee-hive coking industry in the Coast District of British Columbia is at Union Bay, Vancouver Island, where coke has been produced since 1897. Some of the coals of the

*Memior 88—Geological Survey Canada. Geology of Graham Island, B. C., by J. D. MacKenzie.

Comox district are well suited for the production of coke, but ash is high and there is a considerable amount of sulphur which is not eliminated either in the washing or in the coking operations. The coarse sizes of coal produced are usually sold and only the finest sizes are used for coking. The plant of the Canadian Collieries (Dunsmuir) Limited at Union Bay consists of two batteries of 100 ovens each. Ordinarily 72-hour coke is made which is suitable for copper smelting; some special foundry coke is also produced. Analyses of this show low moisture content, volatile matter up to five per cent, ash ranging from 18 to 24 per cent, sulphur from 0.60 per cent to over one per cent, and phosphorus up to 0.09 per cent.

A by-product plant, operated by the Granby Consolidated Mining Smelting and Power Company at Anyox supplies coke for the copper smelting operations at that place. Coal is obtained from a mine on the Douglas seam near Nanaimo on Vancouver Island. Washed slack is shipped to the plant for coking. The installation consists of a thirty-oven coke battery made by the Gas and Coke Oven Company, and equipment for the recovery of gas, tar, ammonia, and oil. Complete analyses of this coke are not available, but it is rumored that the quality of the coke is not entirely satisfactory because of high ash content and because of poor physical structure.

TABLE III

PRODUCTION OF COKE IN COAST DISTRICT OF BRITISH COLUMBIA.*

Year	Coke Produced (Long tons)	Sold for Con- sumption in Canada	Sold for Export to United States	Total Sales
1896	1,240	.....	.....	1,240
1897	17,831.5	14,528.5	2,573	17,101.5
1898	35,000	31,833	3,167	35,000
1899	5,000	1,000	4,000	5,000
1900	19,234	3,476	12,799	16,275
1901	15,938	2,913	15,258	18,171
1902	20,178	3,998	12,016	16,014
1903	15,779	19,498	.....	19,498
1904	19,371	10,333	2,591	12,924
1905	15,661	5,410	4,300	9,710
1906	9,842	14,547	8,304	22,851
1907	16,372	14,592	220	14,812
1908	12,530	2,904	3,118	6,022
1909	13,686	5,493	.....	5,493
1910	2,333	8,327	.....	8,327
1911	.....	6,153	.....	6,153
1912	.....	4,266	.....	4,266
1913	.....	66	.....	66
1914	.....	2,314	.....	2,314
1915	5,450	5,383	.....	5,383
1916	27,604	26,043	.....	26,043
1917	30,406	31,559	.....	31,559
1918	24,653	24,653	.....	24,653
1919	34,071	35,655	.....	35,655

342,179.5

*From Annual Reports of the Minister of Mines for the Province of British Columbia.

UNDEVELOPED RESOURCES OF OREGON
AND ALASKA.

OREGON

The Eden Ridge coal field which lies in Coos county, southwestern Oregon, not far from the coast, contains bituminous coal which in some portions is believed to have coking qualities. Tests made by the United States Bureau of Mines on samples from Squaw Basin gave negative results, although it is reported that selected portions of some beds were coked in a blacksmith forge. * Tests made at the College of Mines, University of Washington, on samples from the northern portion of the field yielded unsatisfactory coke. The meagre data available is not sufficient to justify a final conclusion, but it does not appear that this field contains deposits of coking coals of sufficient extent or quality to make Oregon a factor in any future coke production.

ALASKA

Two important coal areas of Alaska which are of potential interest as sources of coking coal are the Matanuska and the Bering River fields. The Bering River field is sixty miles from Cordova and twenty-five miles from Controller Bay; the Matanuska field is from twenty-five to fifty miles northeast of Knik at the head of Cook Inlet and approximately 100 miles from the town of Seward. Not all the coals in these fields are suitable for the manufacture of coke, but some localities appear to contain areas of bituminous coal of coking grade. These particular deposits will be considered in the following pages.

A portion of the Matanuska field, particularly in the vicinity of Chickaloon River, Coal Creek, and Kings River is known to contain high grade bituminous coal which has good coking properties.† Many of the seams have been badly folded and crushed; but this is an advantage from the standpoint of washing and coking. A rough test of the coking qualities of one of the seams on Chickaloon was made by coking a large pile of coal under a covering of stones and dirt. This is reported to have yielded hard and firm coke which had a good ring and good texture. The test indicated that by proper treatment a coke of satisfactory grade could be produced.

In the Bering River field conditions somewhat similar to those in the Matanuska field are found. The coal in some portions of the field is friable and will yield a large amount of small sizes in mining. Coking tests on the coal from Trout Creek and Carbon Creek were made by G. C. Martin who reports the following:‡

* Bull. 541-i. U. S. Geological Survey. The Eden Ridge Coal Field, Coos County, Ore. by C. E. Leshner.

† Bull. 500. U. S. Geological survey. Geology and Coal Fields of the Lower Matanuska Valley, Alaska, by G. C. Martin and F. J. Katz.

‡ Bull. 335 U. S. Geological Survey. Geology and Mineral Resources of the Controller Bay Region, Alaska. By G. C. Martin.

"The coking qualities of the coal from the 33-foot bed on Trout Creek were tested by the writer in the summer of 1905 in the following manner: A hot wood fire was built in a pit dug for the purpose, and lump coal gradually added until about 600 pounds of coal was burning. Then about a ton of slack and lump coal was added. The sides of the pile were banked with stones and dirt, the top and ends being left open for draft. After several hours the ends were banked and only a small opening at the top was left uncovered to let the smoke escape. Four days later, when the smoke ceased to come off, the pile was opened and the fire extinguished. The resulting coke was firm, strong, porous, and had a good ring and luster. The test showed conclusively that an excellent coke can be made from this coal by proper treatment.

The coal from the 8-foot bed on Carbon Creek was tested in 1906 in the same manner. Heavy rains, during the early part of the test, made it impossible to get as hot a fire as should have been used, and the test was consequently not as great a success as was hoped for. A small quantity of fair quality of coke was obtained from the center of the pit, which seems to indicate that, under more favorable conditions, good coke could be produced.

Coal from many of the other seams was tested more crudely, and it was found that practically all of the coal here classed as semi-bituminous possesses such coking qualities that probably by proper treatment a good coke can be made from almost any of it."

Samples of Chickaloon and Eska Creek coals were sent to the United States Bureau of Mines station at Seattle in 1918 for testing. The Chickaloon coal was given washing tests at two of the coal washeries in the state, after which one of the products was coked. The results of the coking test are summarized below:*

A sample of Chickaloon coal weighing 12,225 pounds, which had previously been washed, was charged into a standard bee-hive oven at the plant of the Wilkeson Coal & Coke Company. The coking period was slightly less than 96 hours. Analyses of the sample and the resulting coke are as follows:

	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur
Coal	1.00%	22.52%	65.87%	10.61%	0.49%
Coke	0.55	0.70	85.45	13.30	0.57

The resulting coke was large in size and of good appearance. The yield was low, approximately 50 per cent. The coke from the test was shipped to a local foundry which reported that it was suitable for foundry purposes.

A distillation test on a sample of the washed coal made by the H. Koppers Company at the laboratory of the Mellon Institute is reported in part as follows:

*Information received from E. R. McMillan, Assistant Mining Engineer, United States Bureau of Mines. Work performed at Seattle Station, under direction of Geo. W. Evans partly in cooperation with College of Mines, 1918.

Practical yields per net ton of coal:

Tar (gallons)	4.4
Sulphate (pounds)	20.0
Gas (cubic feet) at 15° C, 760 mm. Hg.....	10850.0
Coke (per cent of coal).....	81.3
Light oil (gallons)	1.9
Light oil is estimated to contain 55% Benzol and 12% Toluol. Specific gravity of gas 0.30; heating value in gas per pound of coal 2979 B. t. u.	

The Alaskan coals described are of high rank, bituminous and semi-bituminous, and are low in ash. All the evidence points to the fact that they will make coke of high quality, probably superior to the coke now produced in Washington and British Columbia. Their importance as future assets must not be overlooked, but for the immediate present they are not of serious moment in a consideration of the coking situation in the Pacific Northwest. High mining costs will undoubtedly prevail, the additional expense of preparation and transportation will be large, and the cost of the coke promises to be greater than that produced in the older established districts. On the other hand, in the interim elapsing before development begins in Alaska on a commercial scale, economic factors will have changed in British Columbia and in Washington. This may eliminate many of the differentials and give the Alaskan coal and coke an opportunity to compete successfully in the southern market.

STATUS OF THE COKE INDUSTRY

In the preceding pages the known facts relating to the distribution of coking coals, history, coking practice, analyses, markets, and production statistics of the coking industry of the Pacific Northwest have been reviewed. Washington and British Columbia are the only producers of coke west of the Rocky Mountains except Utah, which is not tributary to the territory discussed.

Bee-hive coke constitutes the great bulk of the production, although two by-product plants in operation, one of which is operated primarily for the manufacture of illuminating gas and the other for the production of smelter coke. The greater portion of all the coke manufactured is used in the copper smelters of Washington and British Columbia, only a small amount entering the California market for use in non-ferrous smelting. Coke for foundry purposes and for general industrial use makes up a smaller proportion of the output.

The market field is restricted because of demand from a comparatively few users, such as the copper and lead smelters of the coast, and the limitations of the product itself. High ash coke which demands a fairly high price at the ovens cannot successfully enlarge its market territory in competition with better, cheaper coke. The question of establishment of new metallurgical industries on the coast will be govt-market for the product. In this connection the coke question is important. It is reasonably safe to say that suitable coke can be supplied for such industries, but that the fuel cost will be high. In the final analysis, the matter resolves itself into one of costs.

California and Oregon cannot be regarded as factors in future coke production. Alaska contains high grade coking coals which at present are but slightly developed and remote from cheap transportation, but this territory must be considered as the reserve from which future supplies will be drawn to meet the demand which must inevitably come as the resources of the coast areas are brought into active production. Until then the established coking plants in Washington and British Columbia will continue to be the main sources of supply of this necessary fuel.

One of the most important matters facing the industry, in addition to the question of suitable supplies of coal, is the problem of future coking practice. Bee-hive oven practice with its waste of valuable products represents a great economic loss which should not be encouraged. By-product practice, on the other hand, demands greater initial plant expenditure and is dependent on a continuous and assured market for its products for economic operation. The quality of the coke produced by either must be given further study, not merely from the chemical standpoint but from the standpoint of physical structure and properties. The data on this latter subject are extremely limited, although it is one of the first questions looked into by the prospective user of coke. The possibilities of mixing coals to produce the desired qualities in coke must also be given more detailed attention.

In short the technical phases of operation practice, particularly in the case of by-product coking, need considerable scientific investigation in order that the scattered resources of coking coal may be utilized to the fullest benefit of all the industries involved. One of the keys to the door of metallurgical and industrial establishment in the Pacific Northwest is coke. Any improvements in the quality of product will be reflected in the growth of the coke industry and in the chain of other lines of activity which depend upon this basic substance.

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ENGINEERING EXPERIMENT STATION SERIES

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AN INVESTIGATION OF
COMPRESSED SPRUCE PULLEYS

BY

GEORGE SAMUEL WILSON

Associate Professor of Mechanical Engineering



SEATTLE, WASHINGTON
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AN INVESTIGATION OF COMPRESSED SPRUCE PULLEYS

With the view of determining the practicability of manufacturing pulleys from native spruce, a series of tests were conducted in the Mechanical Engineering Laboratories of the University of Washington. These tests extended over a period of nine (9) months from July 1, 1919 to April 1, 1920. The investigation included the following:

1st. Determining some of the factors influencing the carrying capacity of compressed spruce pulleys;

2nd. A comparison of compressed spruce pulleys with other commercial types.

The work was undertaken at the request of Watts & Walsh, of Tacoma, Washington, Manufacturers of Compressed Spruce Power Transmission and Conveying Equipment. A large amount of credit is due them for the assistance given in conducting the tests.

The tests were made with single ply leather belting, four (4) inches wide by 0.225 inches thick and 0.9 square inches in cross-section. The pulleys were normally 18 inches in diameter and 6 inch face. A constant speed of 2000 feet per minute was maintained.

Since it was desirable that results obtained in this series of investigations be such that they might be compared as readily as possible with other investigations* on belt pulleys the same general method of conducting the tests were used as are ordinarily employed in standard practice.

In general the tests consisted of sets of observations on belt slips (slip includes creep) at different initial belt tensions and varying brake loads. Five different initial tensions were used in each set, and the load varied from a minimum to the maximum that the belt would carry or the capacity of the driving motor would allow.

In order to get results which might be considered a fair measure of the pulley capacities, several sets of tests were made under conditions as nearly alike as possible and the results averaged.

*Tests of the Transmitting Capacities of Different Pulleys in Leather Belt Drives, by Professor W. H. Sawdon.

THE TESTING MACHINE

The machine used in the tests was built for the Mechanical Engineering Department of the University of Washington. Figure 1 shows the general arrangement.

The machine consists of the following elements: driving shaft; tension weighing device; arc of contact meter; slip meter and a driven shaft and Prony brake mounted on an adjustable carriage.

(A) is the driving pulley; (B) a Universal coupling; (C) the tension weighing device; (D) the arc of contact meter; (E) the driving test pulley; (F) the driven test pulley and (G) the Prony brake and tension adjusting device.

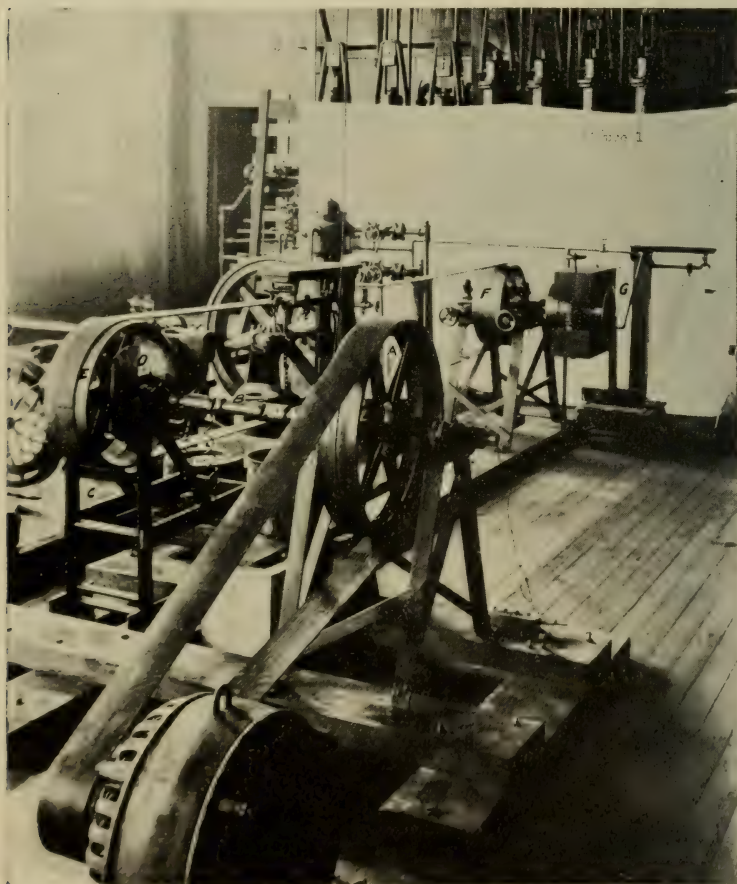


Figure 1

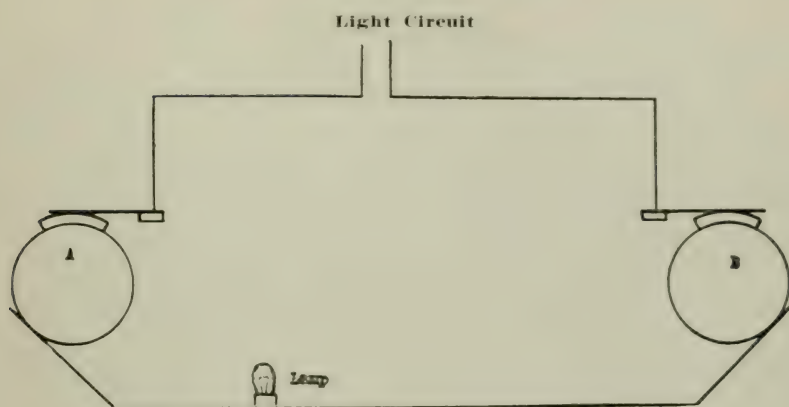


Figure 2—Slip Meter

Figure 2 shows the slip meter used and is similar to the meter in use by Professor S. H. Graf of the Oregon State Agricultural College. The two cams, A and B, come into contact with the electrical connectors once each revolution. When the cams are in phase, the light flashes once each revolution; as the driven shaft lags behind the driving shaft, the cams gradually get out of phase and the light goes out until the driven shaft has dropped one full turn behind the driving shaft when the light starts flashing again. To determine the slip a continuous counter, operated by the driving shaft, was started at the first light flash and was allowed to run until the light had died out; when the light again began to flash, the counter was stopped. The reading obtained was the number of revolutions made by the driving shaft for the loss of one revolution of the driven shaft.

OBSERVATIONS

The initial tension was adjusted and taken at the beginning of each test for four positions of the driving shaft, 90 degrees apart. The average of the four weights was used as the initial tension. The machine was started and brought up to speed and the first brake load applied. The running tension, arc of contact and slip measurements were then made. The next higher load was then applied and the same observations taken until the maximum load the belt would carry or the driving motor could safely stand was reached. The machine was then stopped and the belt tension was again determined in the same manner as at the beginning of the test.

FACTORS AFFECTING THE CARRYING CAPACITY OF
COMPRESSED SPRUCE PULLEYS

Complete log sheets were kept and report sheets calculated for all tests made. The great amount of material accumulated made it desirable to include in this paper, for the qualifying tests at least, only graphical sheets. The graphical sheets show slip plotted against net brake load for the nominal initial tensions $37\frac{1}{2}$, 75, $112\frac{1}{2}$, 150 and $187\frac{1}{2}$ pounds per square inch of belt section.

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Figure 3 shows the results obtained with compressed spruce pulleys made with 1" laminations, all end grain surface, put together with very little pressure and natural surface on the face.

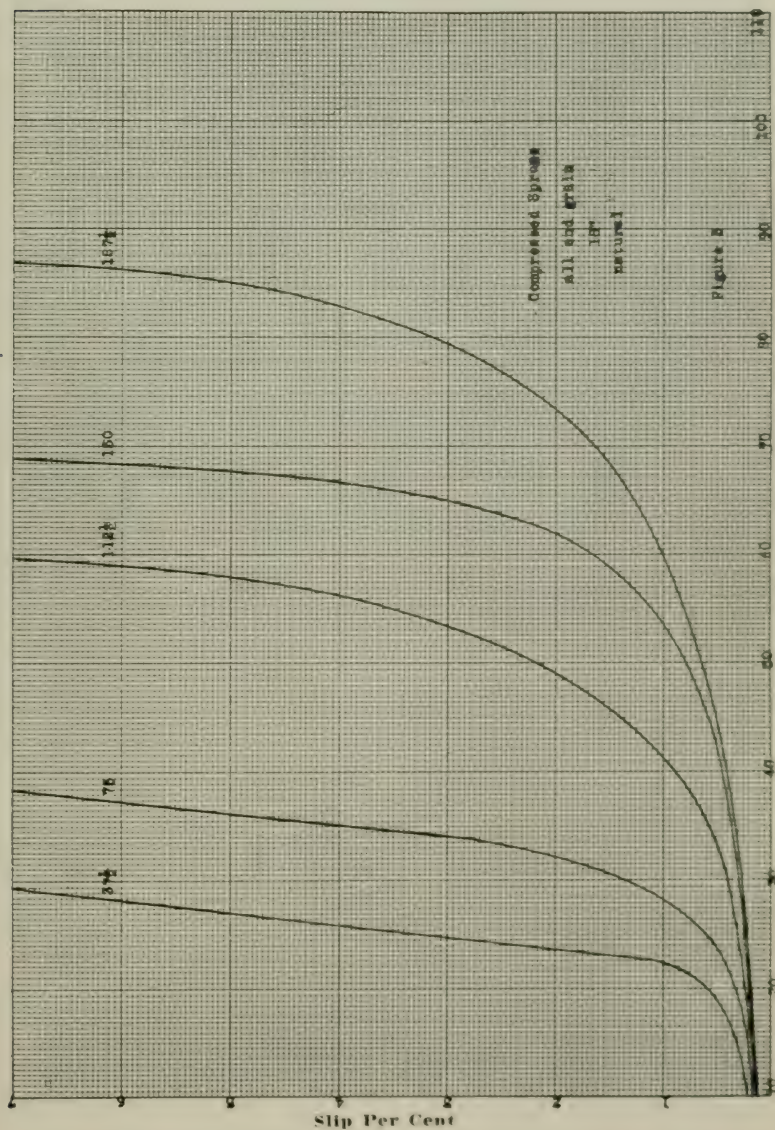


Figure 3—Net brake load lbs.

Figure 4 shows the results obtained with the same pulleys as in Figure 3 but several coats of high grade shellac had been applied to the face of the pulleys.

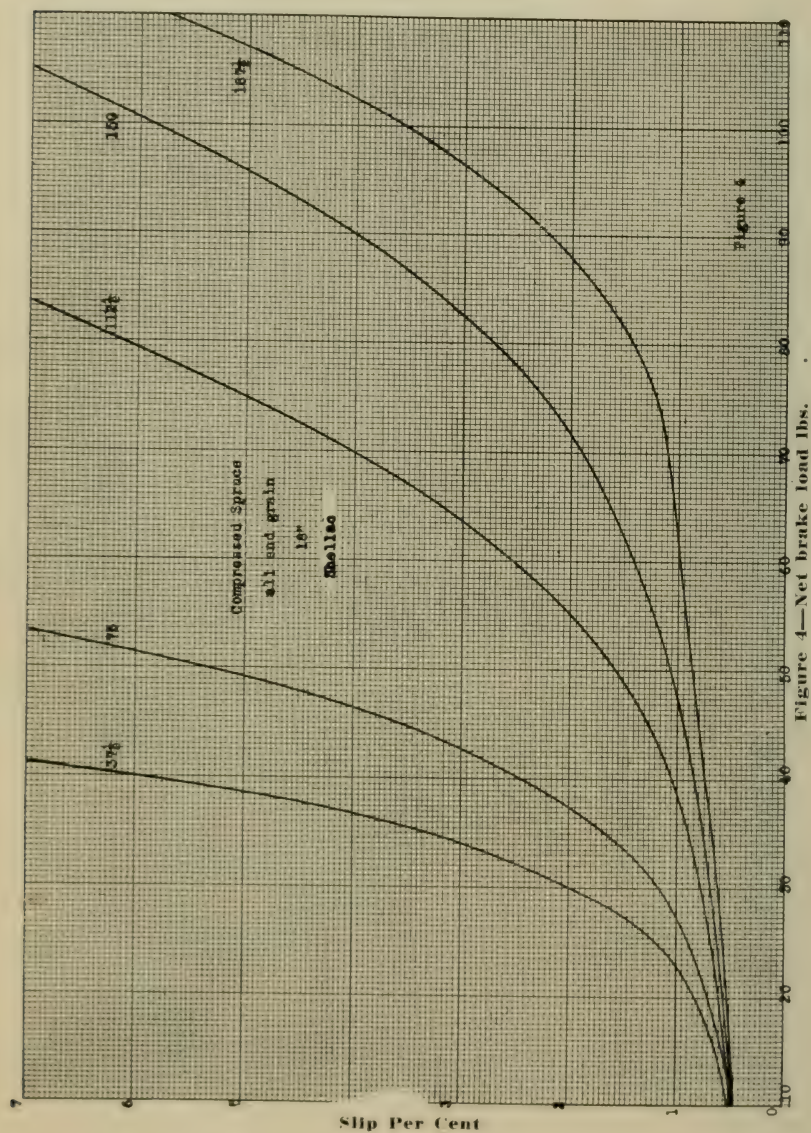


Figure 4—Net brake load lbs.

Figure 5 shows a comparison made with the pulleys used in Figures 3 and 5 at the nominal belt tension of 150 pounds per square inch of belt section.

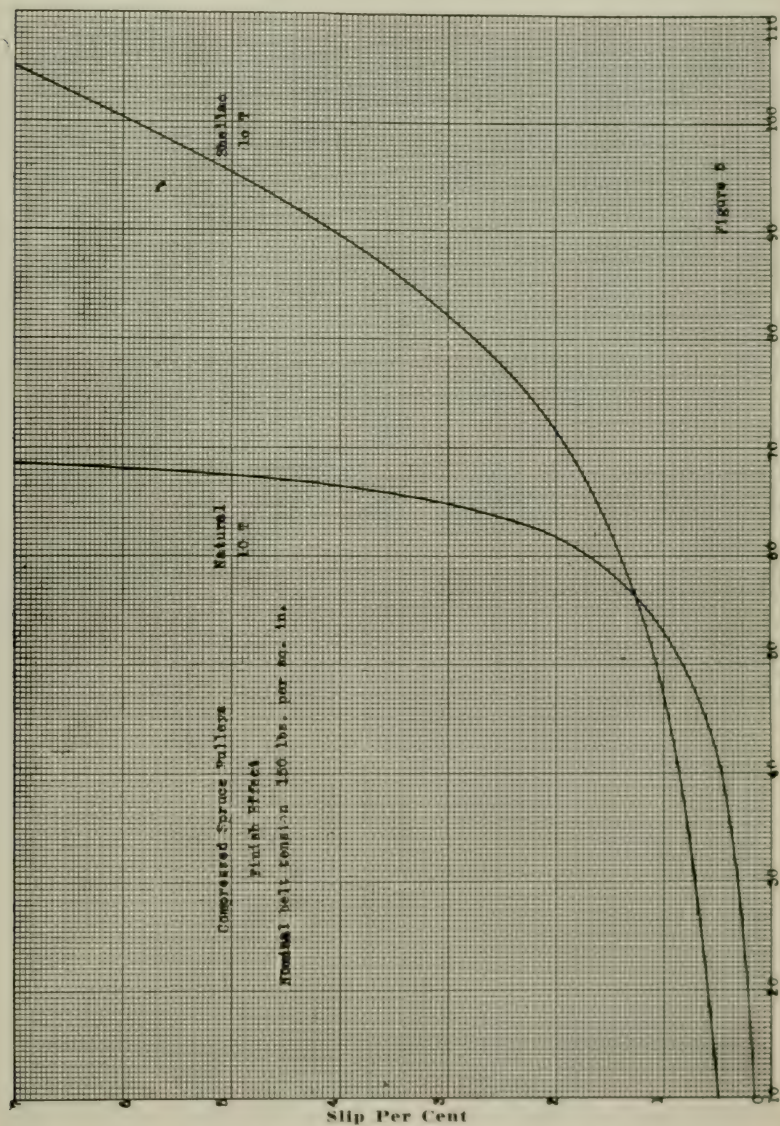


Figure 5—Net brake load lbs.

Messrs. Watts and Walsh decided at this point to discontinue the development of all end grain pulleys and to develop a 50 per cent. end grain pulley built with about $\frac{1}{4}$ " laminations.

Figure 6 shows the results obtained with the 50 per cent. end grain pulleys put together with 10 tons pressure—total pressure on 18 inch pulley.

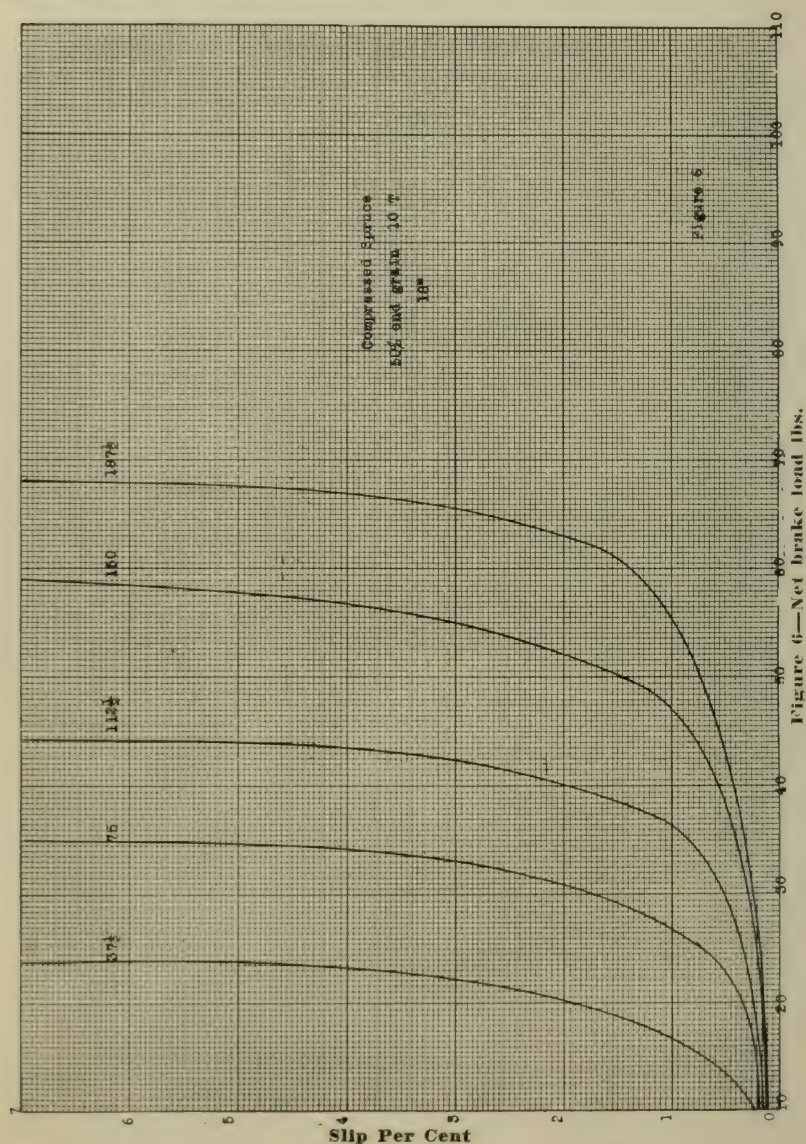


Figure 7 shows the results obtained with the 50 per cent. end grain pulleys put together with 100 ton pressure—total pressure on 18 inch pulley.

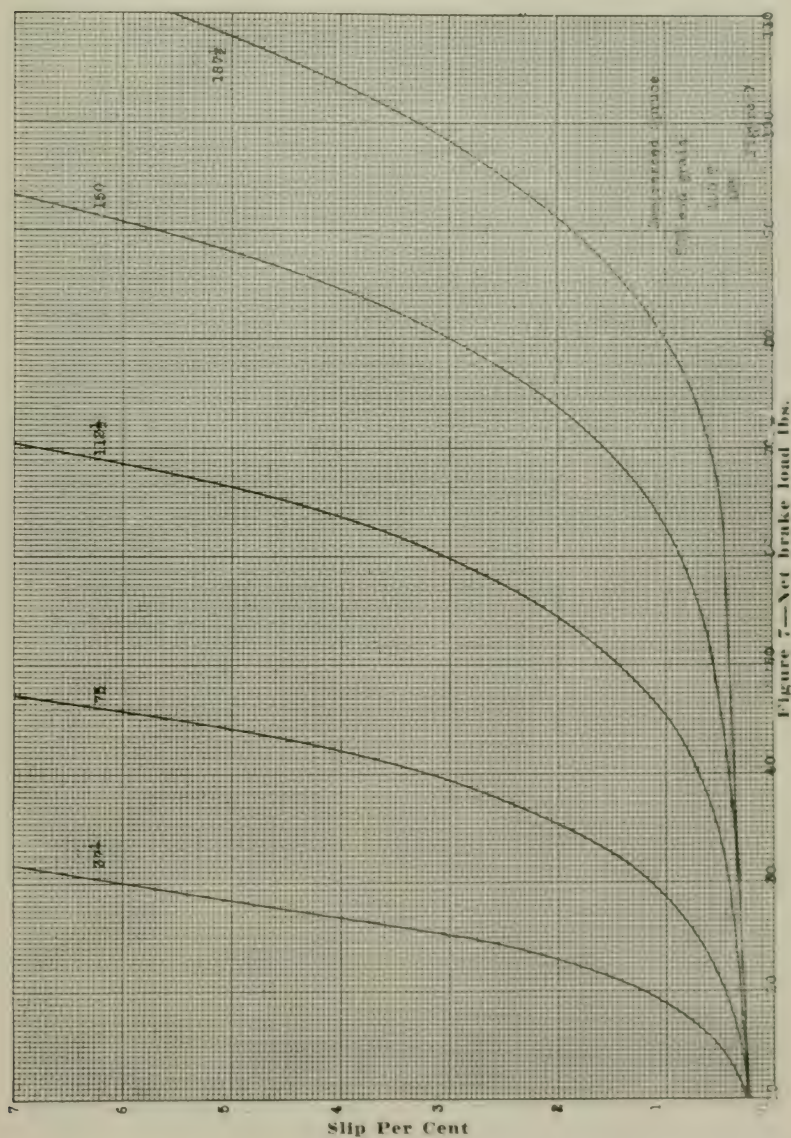


Figure 7—Net brake load lbs.

Figure 8 shows the results obtained with the 50 per cent. end grain pulleys put together with 200 ton pressure—total pressure on 18 inch pulley.

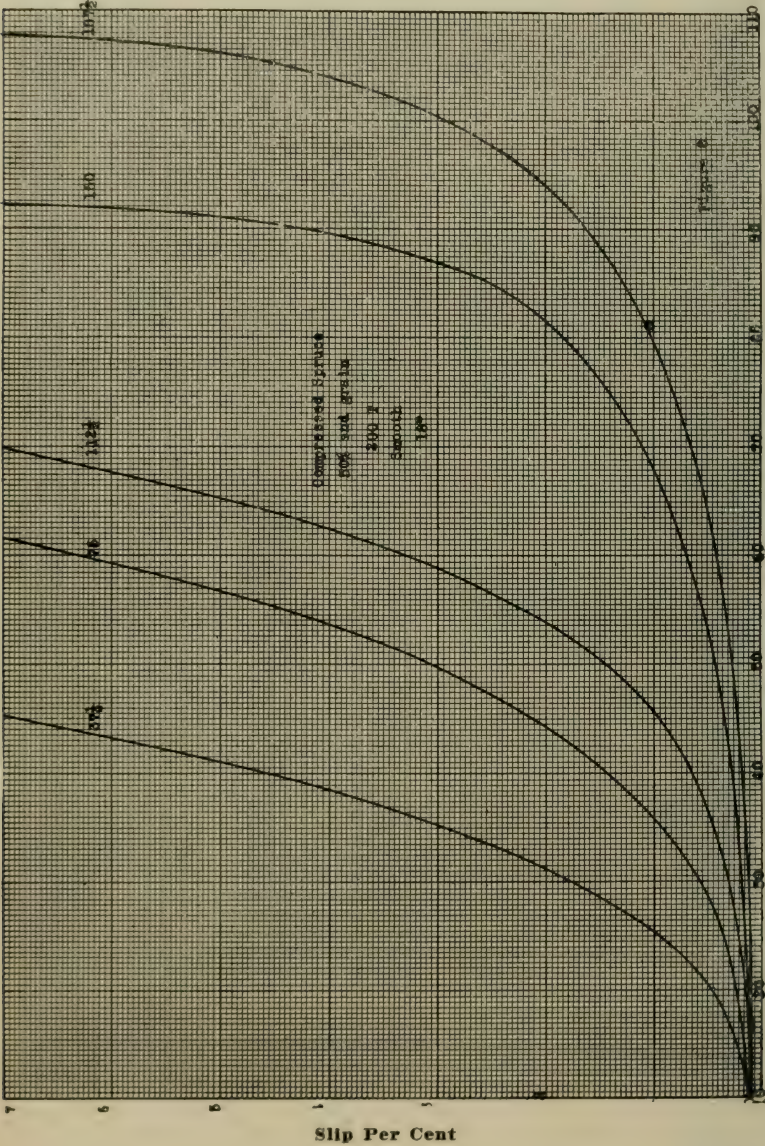


Figure 8—Net brake load lbs.

Figure 9 shows the results obtained with 50 per cent. end grain pulleys put together with 250 ton pressure—total pressure on 18 inch pulley.

The pressure of 250 tons being the greatest that was available at this time, no attempt could be made to test pulleys made with a higher pressure.

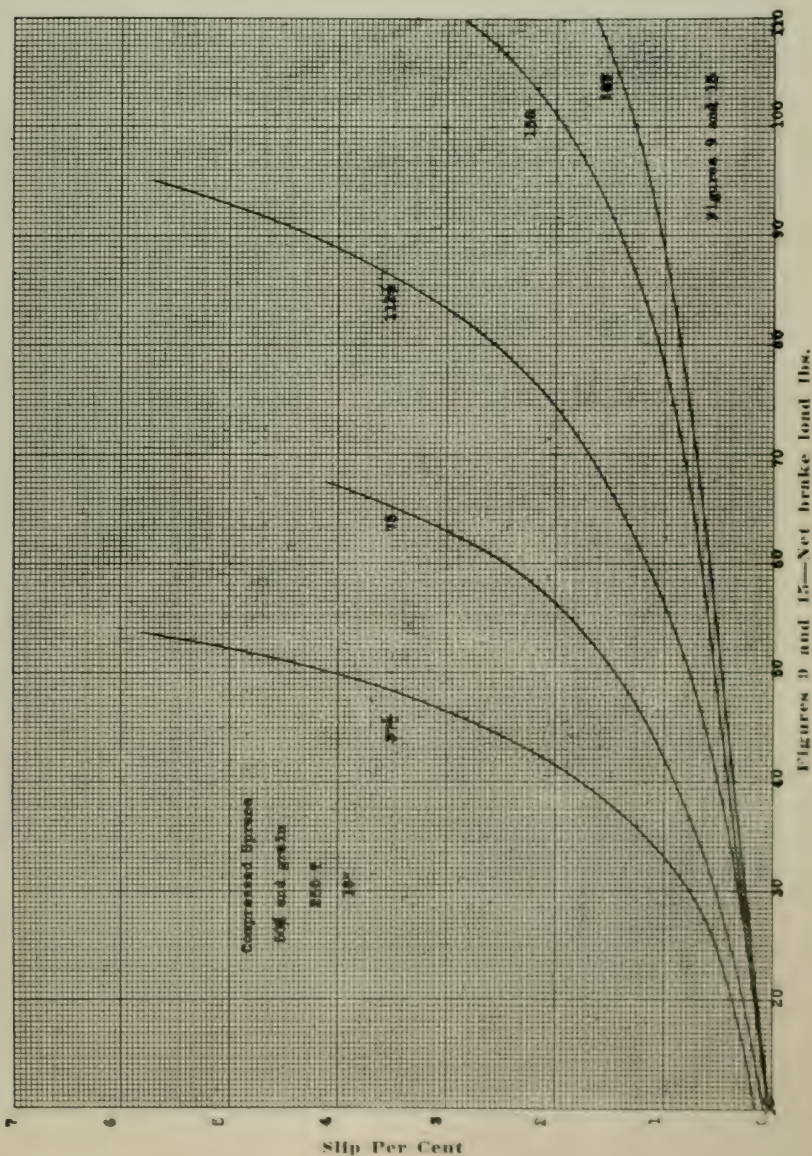


Figure 10 shows the slip curves obtained with the 50 per cent. end grain pulleys at the various pressures and with a nominal initial belt tension of 150 pounds per square inch of belt section.

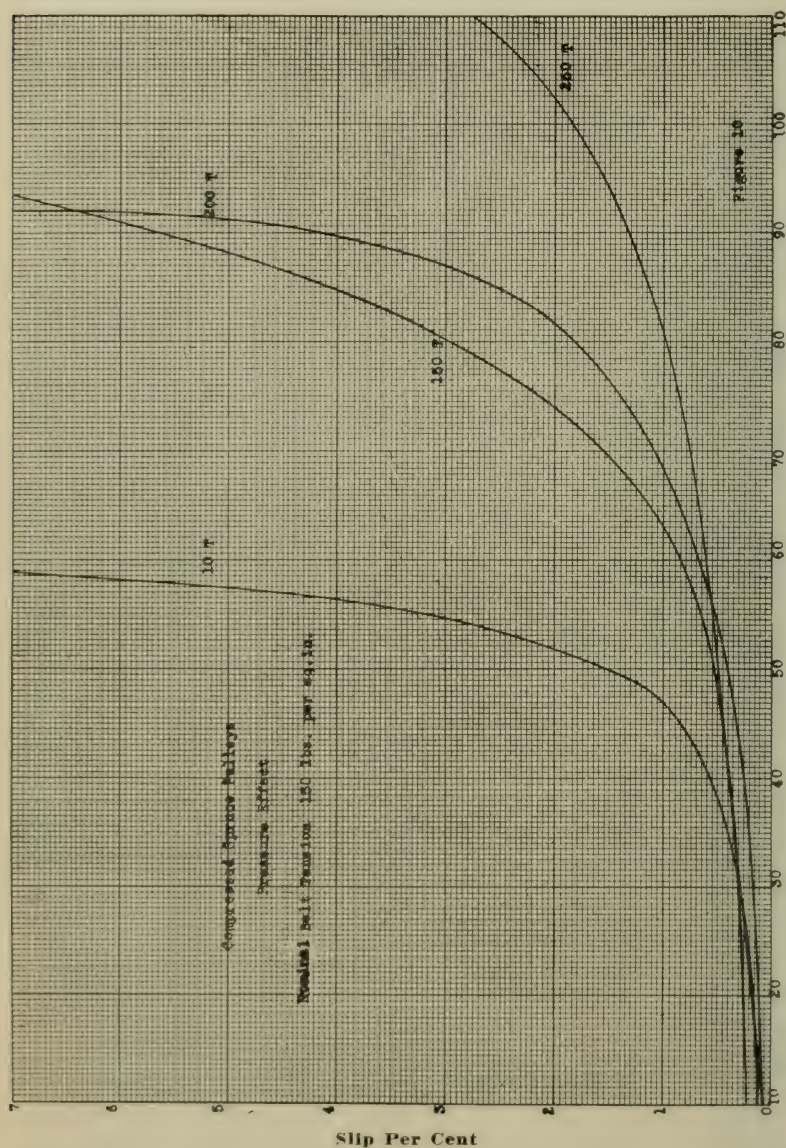


Figure 10—Net brake load lbs.

Figure 11 shows the results obtained with a 50 per cent end grain pulley with a rough finished face and put together with 200 tons pressure.

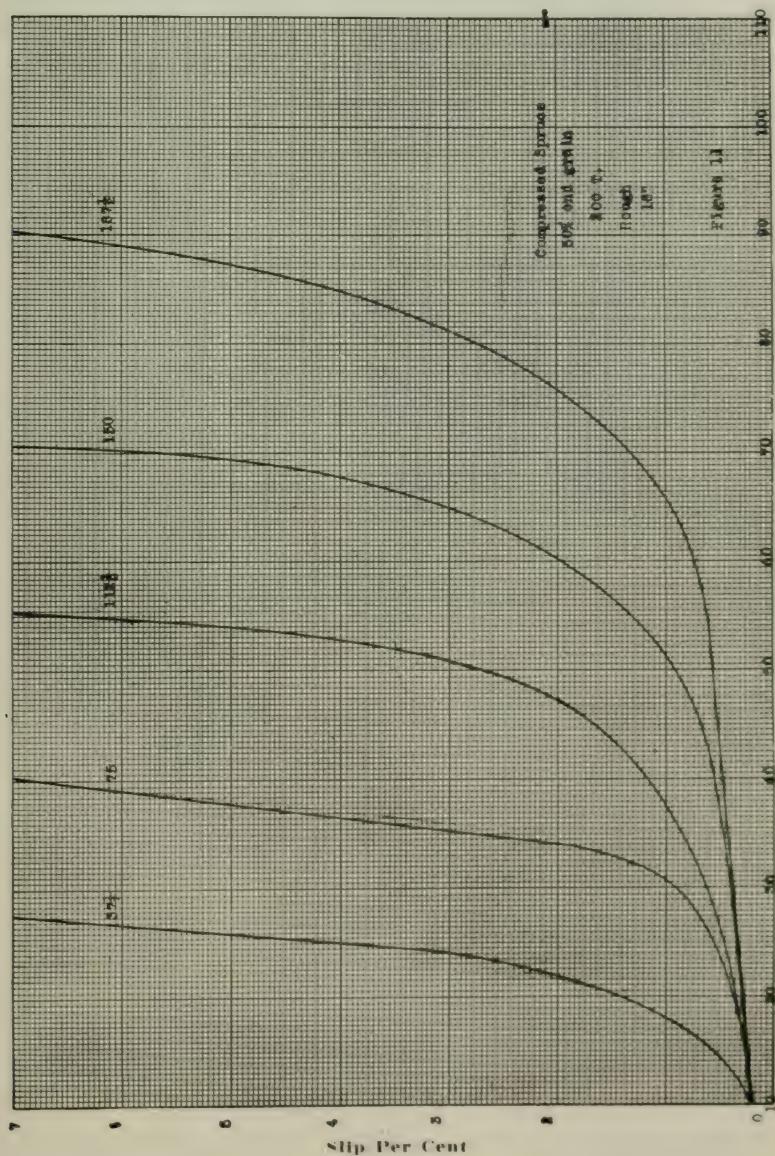


Figure 11—Net brake load lbs.

Figure 12 shows the results obtained with the 50 per cent end grain 200 ton pulley for the rough and smooth faces.

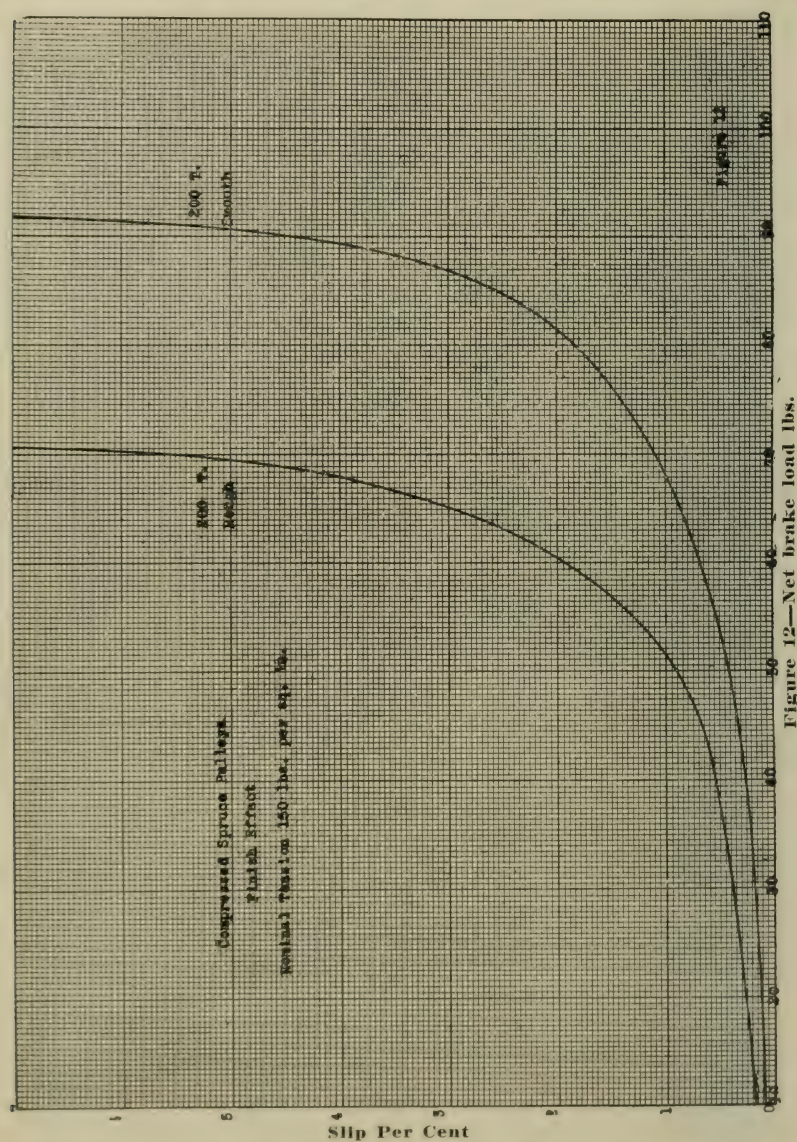


Figure 12—Net brake load lbs.

It was realized that part of the effects due to varying pressures and the condition of the face of the pulley might be partially due to other causes than the ones under direct control. It was decided that

the 50 per cent end grain compressed spruce pulley, built with 250 ton total pressure with the face properly crowned, smoothly finished, and coated with high grade shellac, should be used in a comparative series of tests with other commercial pulleys.

Figure 13 shows the original end grain pulley and Figure 14 shows the pulley finally selected to be used in the comparative tests.

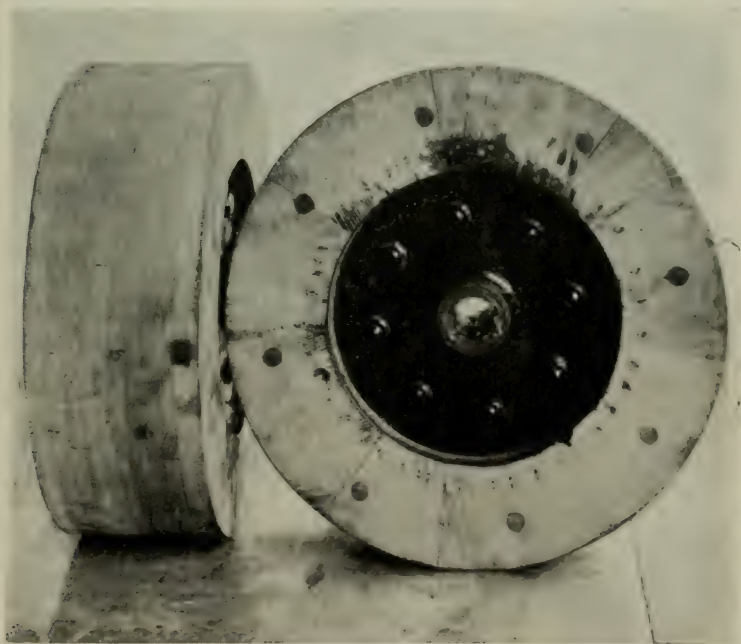


Figure 13

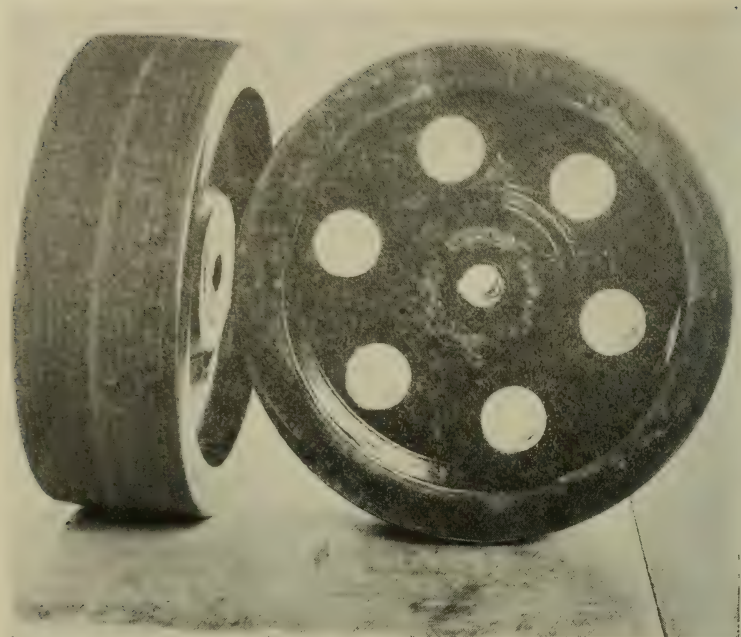


Figure 14

COMPARATIVE TESTS

Using the compressed spruce pulley developed by the preliminary series of runs, comparative tests with compressed spruce pulleys, steel pulleys, split wood pulleys, paper pulleys and cast iron pulleys were made. The log sheets, report sheets and method of reducing data, follow:

COMPRESSED SPRUCE PULLEYS

$\frac{1}{4}$ " Laminations 250 Ton 50% end grain

Dia. Driver=17 15/16

Dia. Follower=17 15/16

Net Brake Load	Revolutions	Flickers	Net Tension Running	Arc of Contact	Initial Tension	Slip %	Slip Curve
5	2322	1	99	185	112	0.04	0.10
10	603	1	101	185		0.17	0.17
20	488	2	110	186		0.41	0.39
30	394	3	126	188		0.76	0.78
40	496	9	145	190		1.81	1.80
45	435	11	152	191	110	2.53	2.53
5			138	184	158	0.04	0.05
10	1206	1	140	184		0.08	0.08
20	366	1	145	185		0.27	0.27
40	342	3	161	186		0.88	0.91
50	449	7	176	188		1.56	1.45
60	402	10	190	190	148	2.45	2.45
5			229	184	249	0.04	0.01
20	596	1	229	184		0.17	0.17
40	394	2	229	185		0.51	0.52
60	347	4	239	187		1.15	1.15
80	233	6	261	189	232	2.58	2.58

COMPRESSED SPRUCE PULLEYS

 $\frac{1}{4}$ " Laminations 250 Ton 50% end grain

Net Brake Load	Revolutions	Flickers	Net Tension Running	Arc of Contact	Initial Tension	Slip %	Slip Curve
5			295	183	322	0.04	0.03
20	745	1	291	183		0.13	0.13
40	484	2	291	184		0.41	0.42
60	409	3	300	185		0.73	0.67
80	379	4	315	186.5		1.05	1.05
100	311	6	339	188		1.93	1.93
110	137	4	347	189	285	2.92	2.84
5			367	182	398	0.04	0.02
20	882	1	361	182		0.11	0.13
40	584	2	356	183		0.34	0.35
60	328	2	358	184		0.61	0.60
80	337	3	368	185		0.89	0.87
100	318	4	380	187		1.26	1.27
110	250	4	385	188	357	1.60	1.64

COMPRESSED SPRUCE PULLEYS
1/4" LAMINATIONS—250 TON—50% END GRAIN

Net Brake Load	Tension per sq. in. belt section		Tension Per Sq. In. Curve	T ₁ —T ₂		T ₁ +T ₂		T ₁	T ₂	$\frac{T_1}{T_2}$	Arc of Contact Degrees	% Slip Curve	Coefficient of Friction
	Initial	Observed		Initial Tension — 37½ lbs. per sq. in. belt section		Initial Tension — 75 lbs. per sq. in. belt section							
5	56.4	49.7	42.0	13.3	75.5	44.4	31.2	1.43	184.8	0.12	0.11		
10	56.2	50.7	42.5	26.7	76.5	51.5	24.9	2.07	185.0	0.25	0.23		
20	56.0	55.3	44.0	53.4	79.2	66.3	12.9	5.14	185.8	0.50	0.51		
30	55.8	63.4	54.0	80.1	97.2	88.6	8.6	10.32	187.5	1.26	0.71		
40	55.6	73.0	66.0	106.8	118.5	112.7	6.0	18.78	189.7	2.87	0.88		
45	55.5	76.4	72.0	120.1	129.4	124.6	4.8	25.96	191.2	3.40	0.97		
Initial Tension — 75 lbs. per sq. in. belt section													
5	79.5	69.4	68.0	13.3	122.3	67.7	54.5	1.24	184.0	0.06	0.07		
10	79.1	70.5	68.5	26.7	123.0	74.9	48.2	1.55	184.1	0.11	0.14		
20	78.2	73.0	70.0	53.4	125.9	89.7	36.2	2.48	184.5	0.27	0.28		
30	76.4	81.0	80.5	106.8	144.8	125.8	19.1	6.58	186.2	0.97	0.58		
50	75.4	88.5	88.5	133.5	159.0	146.2	12.9	11.33	187.8	1.45	0.74		
60	74.4	95.5	95.5	160.2	171.6	166.0	5.8	28.62	190.0	2.35	1.00		
Initial Tension — 112½ lbs. per sq. in. belt section													
5	125.2	115.2	99.5	13.3	179.0	96.2	82.9	1.16	183.6	0.05	0.05		
20	123.7	115.2	102.0	53.4	183.6	118.5	65.1	1.82	184.1	0.18	0.19		
40	121.5	115.2	105.0	106.8	189.0	147.8	41.2	3.59	185.1	0.53	0.39		
60	119.5	120.4	115.0	160.2	207.0	183.6	23.4	7.84	186.7	1.07	0.63		
80	117.5	131.5	128.0	213.0	230.4	222.0	8.4	26.43	189.0	2.90	0.99		

COMPRESSED SPRUCE PULLEYS
 $\frac{1}{4}$ " LAMINATIONS—250 TON—50% END GRAIN

Net Brake Load	Tension per sq. in. belt section		Tension Per Sq. In. Curve	Initial Tension — 150 lbs. per sq. in. belt section			T ₁ — T ₂	Arc of Contact Degrees	Coefficient of Friction
	Initial	Observed		T ₁ —T ₂	T ₁ +T ₂	T ₁			
	Initial Tension — 150 lbs. per sq. in. belt section								
5	162.0	148.5	136.0	13.3	244.8	129.0	115.8	182.7	0.03
20	159.7	146.2	137.5	53.4	247.3	150.4	97.0	183.1	0.16
40	156.5	146.2	143.0	106.8	257.4	182.1	75.3	184.0	0.45
60	153.3	151.0	148.0	160.2	266.4	213.3	53.1	185.0	0.72
80	150.0	158.2	156.0	213.6	280.8	247.2	33.6	186.5	1.08
100	147.0	170.5	169.5	267.0	305.0	286.0	19.0	188.0	1.85
110	145.3	174.5	177.0	293.7	318.6	306.1	12.5	189.0	2.57
	Initial Tension — 187½ lbs. per sq. in. belt section								
5	200.0	184.5	169.0	13.3	304.0	158.7	145.4	182.0	0.03
20	197.5	181.5	171.0	53.4	307.8	180.6	127.2	182.2	0.11
40	194.6	179.0	175.0	106.8	315.0	210.9	104.1	182.9	0.22
60	190.2	180.0	179.0	160.2	322.2	241.2	81.0	184.0	0.33
80	186.6	185.0	183.0	213.6	329.4	271.4	57.9	185.2	0.48
100	183.0	191.0	191.0	267.0	343.8	305.4	38.4	186.8	1.21
110	181.0	193.5	197.0	293.7	354.6	324.1	30.5	187.7	1.52

The log sheets give a record of the data observed during the test. The column headed "Per cent of Slip from Curve" was obtained by plotting slip in per cent against net brake load and drawing in the average curves as in Figure 15. The slip readings were then measured from the curve and entered on the log sheet.

The first column in the report sheets shows the net brake load in pounds.

The second column shows corrected initial tensions in pounds per square inch of belt section.

The initial tension was rarely found to be the same at the end of the series as at the beginning so corrections were made as in Figure 16. The tension at the beginning of the test was plotted against the smallest load, and the tension at the end of the test against the load next higher than the one actually carried. Straight lines were drawn through these points and the initial tensions corresponding to the various brake loads were measured and recorded.

Column 3 is observed running tensions in pounds per square inch of belt section and is calculated as follows:

The tension weighing device was of such proportions that,

$$T_1 + T_2 = 0.906 S$$

S = net scale reading.

$$T_1 + T_2 = \text{sum of tensions}$$

Belt area = 0.9 square inches.

Then, $T_1 + T_2$ per square inch of belt section = 0.503 S .

Column 4 on the report sheet gives the running tensions per square inch of belt section as corrected, so as to give the running tension corresponding to the initial tensions of $37\frac{1}{2}$, 75, etc. lbs. per square inch of belt section.

Figure 17 shows the method used. Running tensions were plotted against initial tensions for each brake load and smooth curves drawn in. The values, as recorded, were taken corresponding to the exact initial tension.

Column 6, the sum of the tensions, was obtained by multiplying the tension per square inch by the total area; that is, column 4 by 1.8.

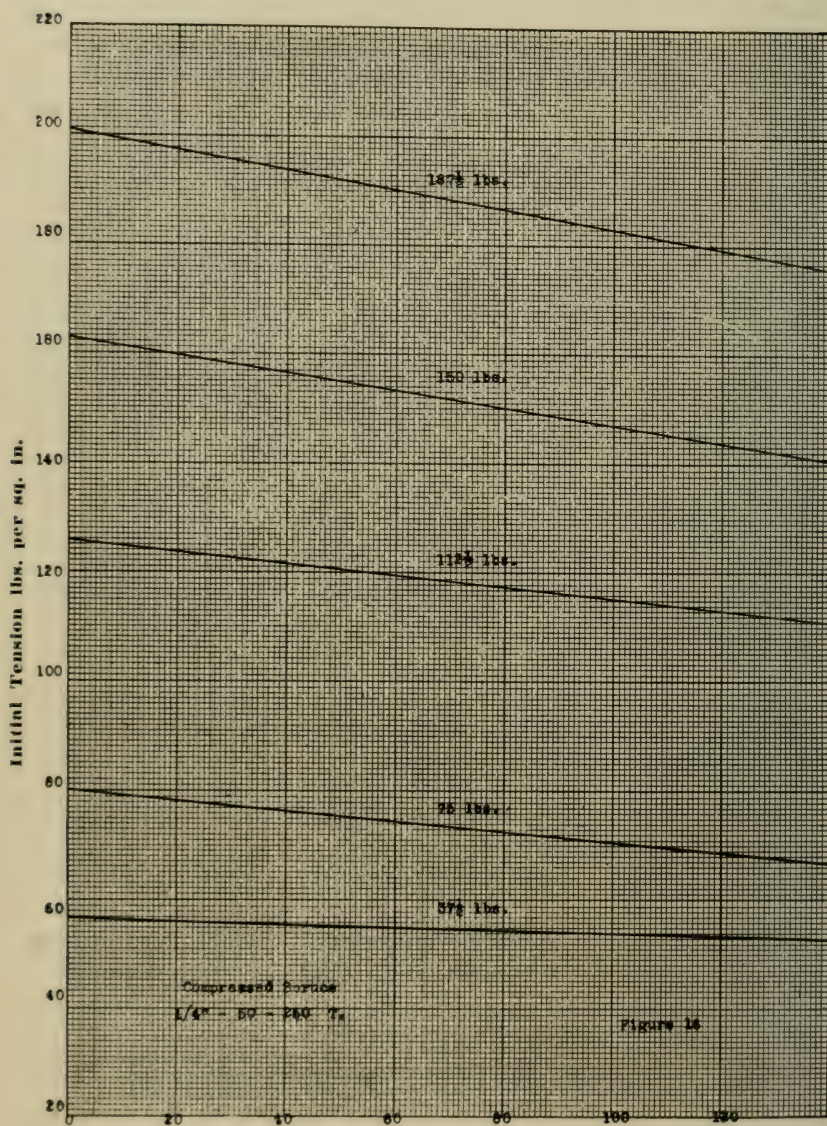


Figure 16—Brake Load

Column 5, the difference of the tensions, was calculated as follows:

Let b = brake arm.

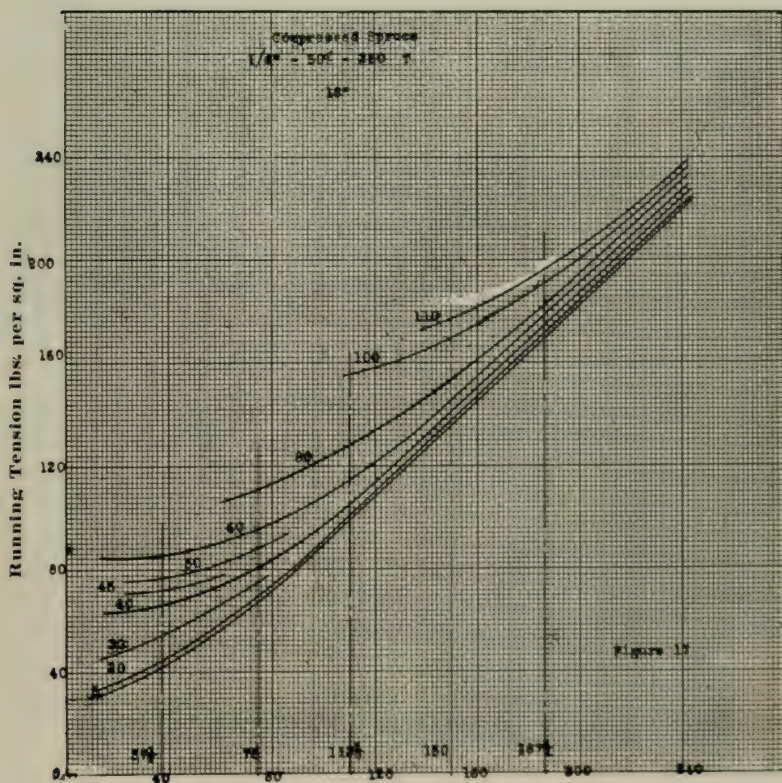
B = net brake load.

D_1 = diameter of driven pulley + thickness of belt.

$T_1 - T_2$ = difference of tensions.

When $T_1 - T_2 = \frac{B \cdot 2b}{D_1}$

$T_1 + T_2$ and $T_2 - T_1$ being known, T_1 , T_2 and $\frac{T_1}{T_2}$ were readily calculated.



Column 10 shows the arc of contact in degrees as obtained from Figure 18. Observed arc of contact readings were plotted against net brake loads and smooth curves drawn. The values in column 10 were then taken directly from the curve for the corresponding brake loads.

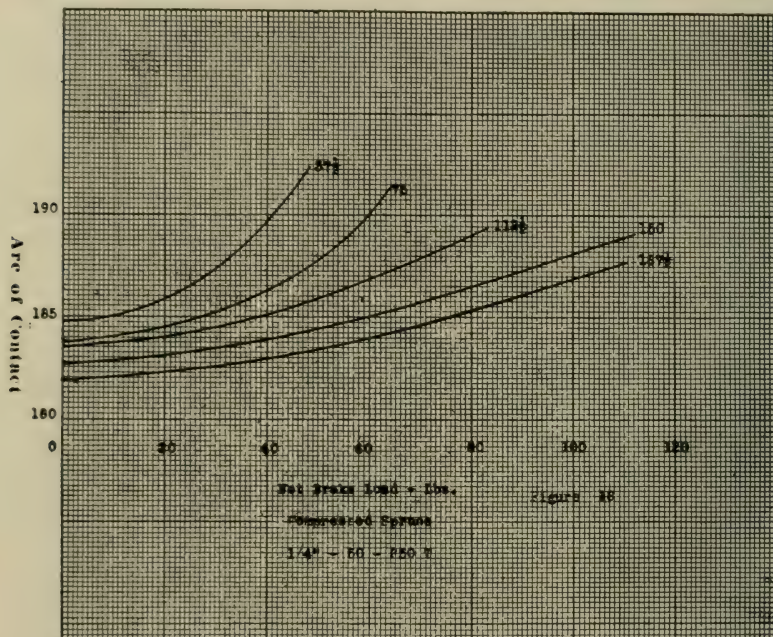


Figure 18—Net brake load lbs.

The values for slip as recorded in column 11 were taken from curves drawn in Figure 19. These curves were drawn by taking the slip readings at the various brake loads and plotting them against observed initial pressures. The slip corresponding to the initial pressure of $37\frac{1}{2}$, 75 lbs., etc., were then taken directly from the curves.

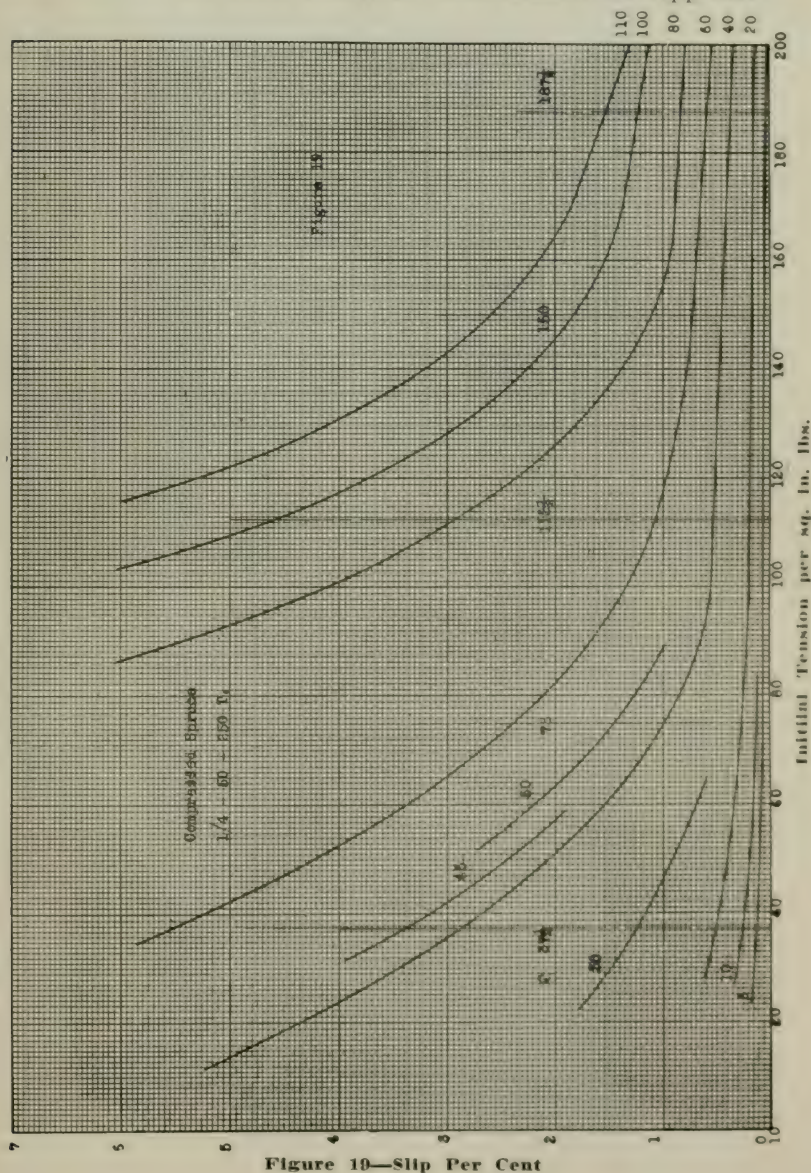
Values of the coefficient of friction as recorded were then calculated as follows:

Let f = coefficient of friction.
 T_1 = tension in tight side.
 T_2 = tension in slack side.
 a = arc of contact in degrees.

Then
$$f = \frac{1}{0.00758a} \log_{10} \frac{T_1}{T_2}$$

Using the values from columns 11 and 12, curves were drawn showing the final relations between slip and coefficient of friction. Figure 20 shows the curves for the compressed spruce pulleys.

Complete log, report and reduction curves used for split wood, steel, cast iron and paper pulleys are to be found in the Appendix.



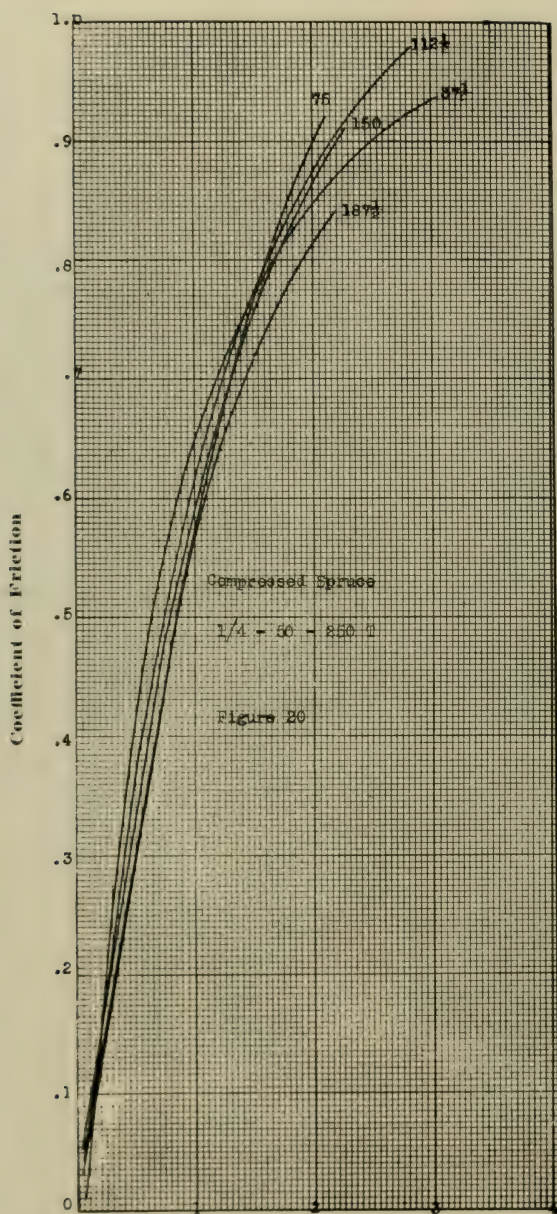
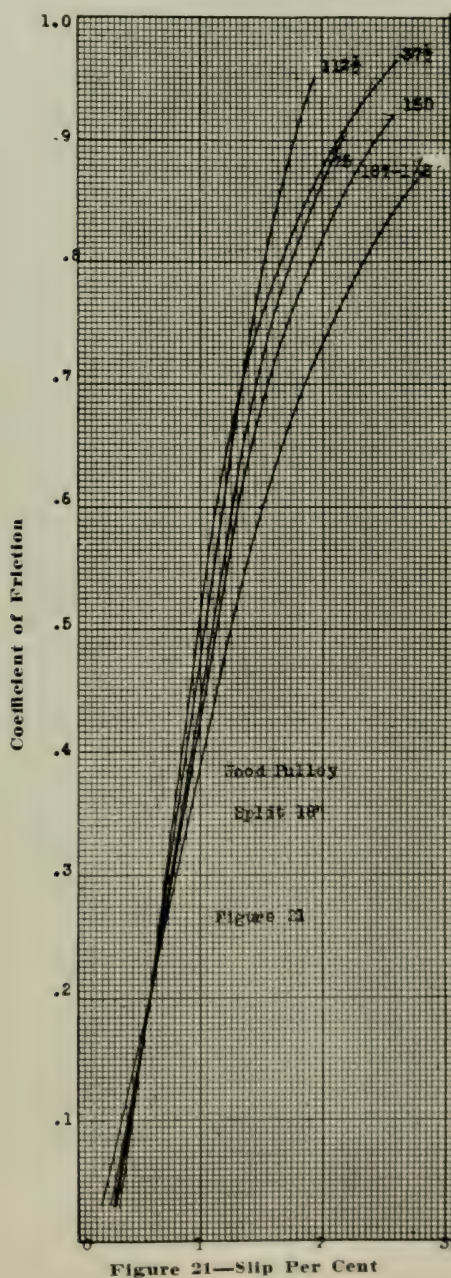
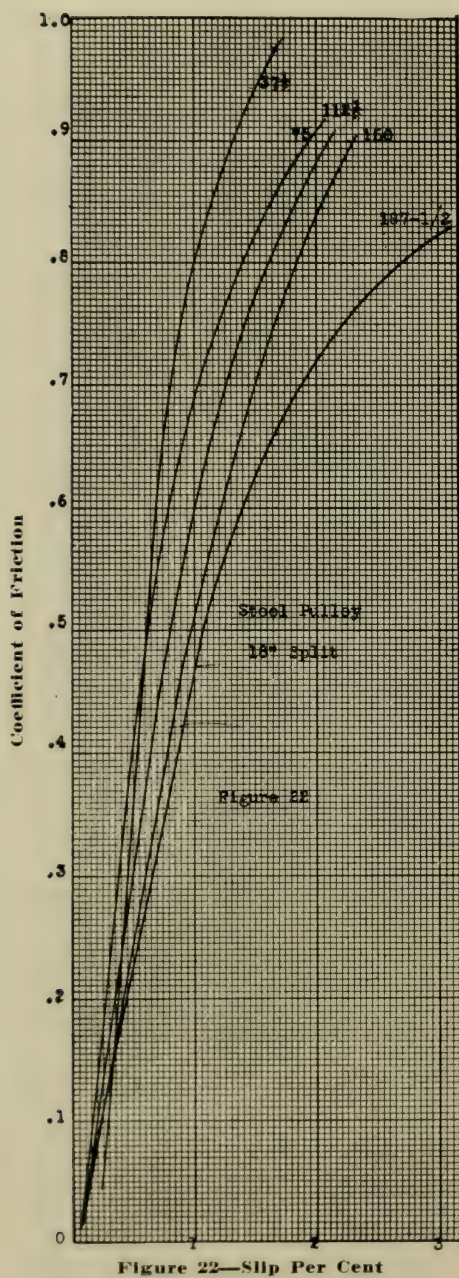


Figure 20—Slip Per Cent

Figures 21, 22, 23 and 24 show the relation between coefficient of friction and slip for the various pulleys.





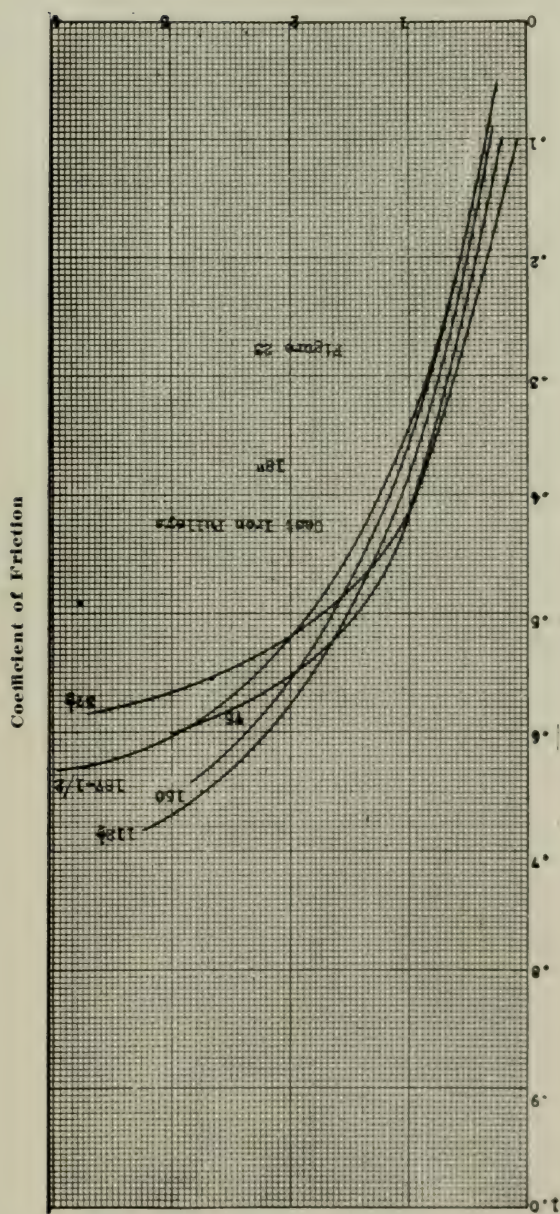


Figure 23—Slip Per Cent

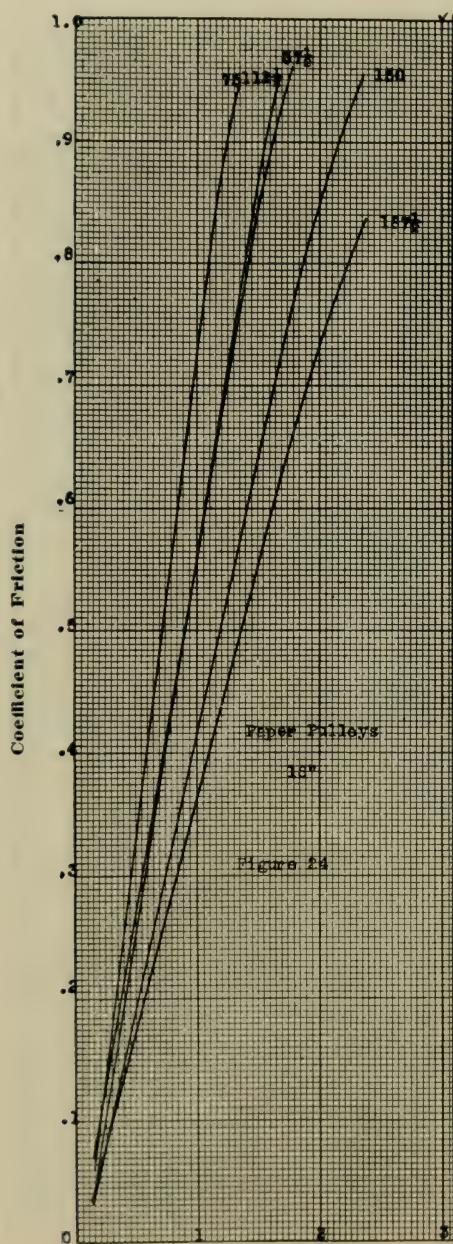
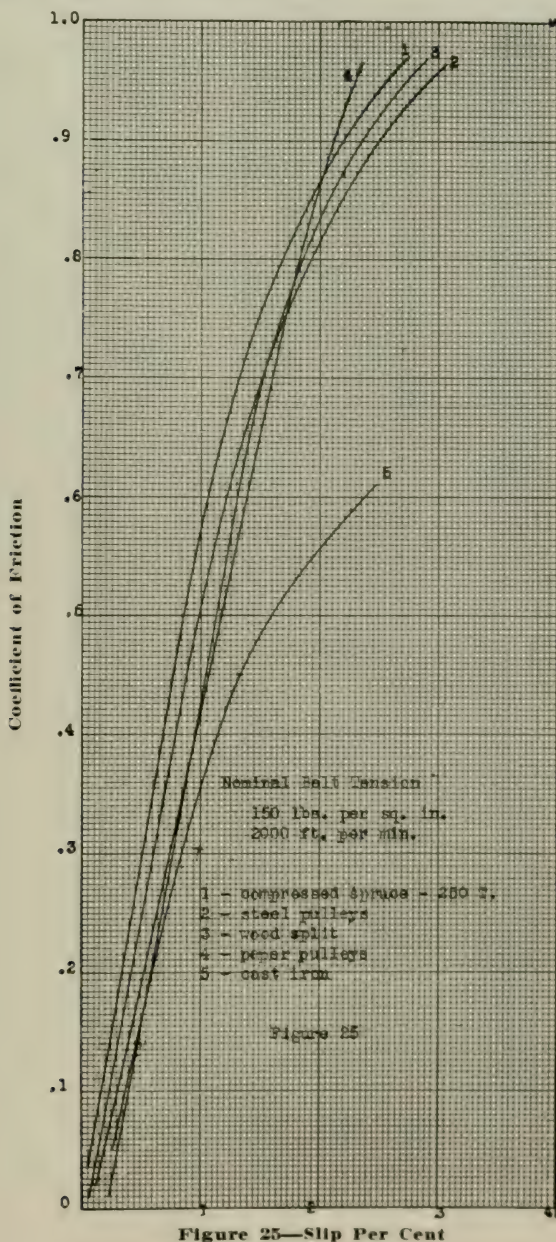


Figure 24—Slip Per Cent

Figures 25 and 26 show the comparative friction-slip relation for the various pulleys at nominal initial tensions of 150 and 187½ pounds per square inch of belt section.



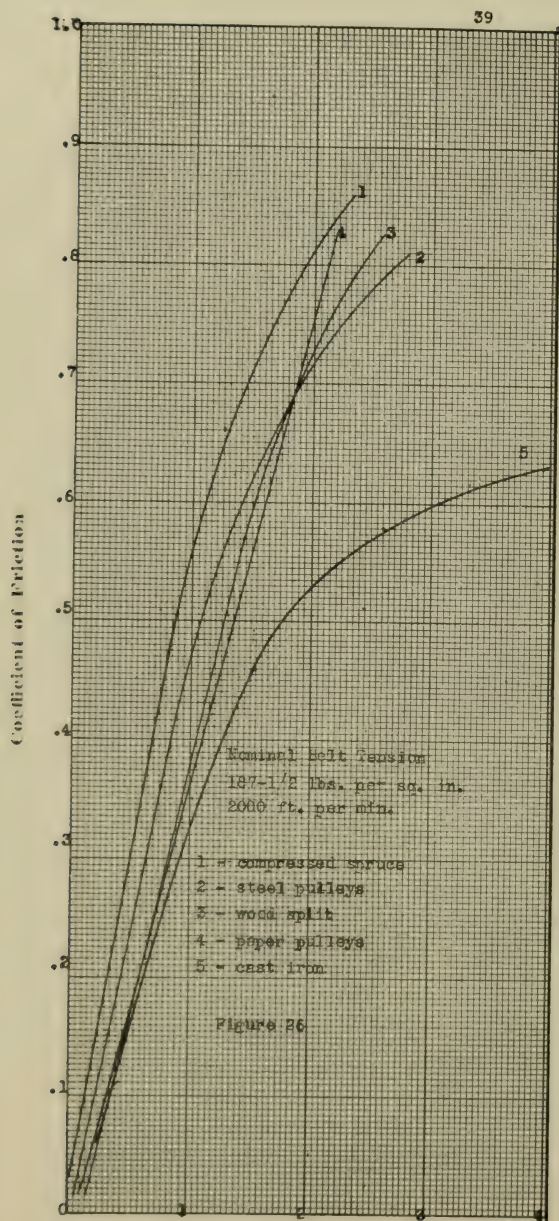


Figure 26—Slip Per Cent

CONCLUSIONS

The preliminary tests indicate that compressed spruce pulleys should be built under pressure and that the face of the pulley should be properly crowned and smoothly finished.

In the comparative tests, the driving motor used in the tests was not of sufficient capacity to load the pulleys to their maximum capacity, but the curves in Figures 25 and 26 show the results within the load limits. It will be noticed that for belt slip below 2 per cent., the variation in the capacity of the different pulleys is small, with the exception of the cast iron pulleys. Cast iron pulleys have the lowest capacity of any of the pulleys tested.

Beyond the 2 per cent slip range the variation is probably greater. In all cases the capacity will be affected by the amount of crown on pulley, the finish of the pulley face and the condition of the belt and belt lacing.

While Figures 25 and 26 serve to give the engineer a definite measure of the pulley capacities, the table in Figure 27 has been worked out to show the horse-power per one inch of width of belt. The table may serve as a handier measure of pulley capacity to the ordinary pulley user.

Horsepower capacities per 1 inch width of belt.

Belt speed=2000 feet per minute.

Maximum stress=200 pounds per square inch cross section.

Arc of contact=180 degrees.

Values of coefficient of friction from Figure 26.

Nagle's formula,—

$$\text{Horsepower} = C F t w \left(\frac{S - 0.12 V^2}{5.50} \right)$$

$$C = 1 - 10^{-0.00758 f a}$$

a =degrees of contact=180

f =coefficient of friction.

w =width of belt.

t =thickness of belt=0.225 inches.

V =velocity, feet per second=33.33.

S =stress in belt, pounds per square inch belt section=200.

Figure 27**Horsepower Capacities per 1 inch Width of Belt**

Pulley	Slip			Comparative Transmitt- ing Capacity at 2% Slip
	1%	1½%	2%	
Cast iron	0.58	0.69	0.74	100.0
Steel	0.71	0.78	0.81	109.4
Wood Split	0.63	0.77	0.82	110.8
Paper	0.62	0.76	0.83	112.1
Compressed Spruce	0.76	0.81	0.84	113.5

Since the weights of pulleys may be a factor in some installations, weights of pulleys were taken and are as follows:

Nominal size of pulley—18" diameter—6" face.	
Cast iron pulley.....	65.0 lbs.
Steel pulley	40.0 lbs.
Wood pulley—split	21.5 lbs.
Paper pulley	41.5 lbs.
Compressed spruce pulley.....	22.0 lbs.

An examination of the capacity table and weight table will show that the compressed spruce pulleys as now developed should prove at least as serviceable as any of the ordinary commercial types.

PAPER PULLEYS

Dia. Driver=17 13/16

Dia. Follower=17 15/16

Net Brake Load	Revolutions	Light Flickers	Net Tension Running	Arc of Contact	Initial Tension	% Slip Correctd for dif- ference in Diam.	% Slip Curve
5	422	4	83.5	185.0	90.0	0.25	0.20
12	422	5	85.5	186.0		0.43	0.35
20	377	5	91.1	187.0		0.63	0.63
30	396	8	95.5	188.0	84.0	1.32	1.24
5	432	4	111.0	184.0	122.5	0.23	0.20
12	381	4	113.0	184.0		0.35	0.25
20	426	5	121.0	185.0		0.47	0.43
30	414	6	123.0	186.0		0.75	0.75
40	384	7	129.0	187.0		1.12	1.12
50	385	9	143.0	189.0	115.0	1.64	1.64
5	436	4	199.0	184.0	227.5	0.22	0.18
20	444	5	200.0	184.0		0.42	0.37
40	411	6	205.0	185.0		0.76	0.76
60	389	7	225.0	186.0		1.10	1.12
70	395	8	238.5	187.0		1.32	1.32
80	398	9	250.5	188.0	217.0	1.56	1.57

PAPER PULLEYS

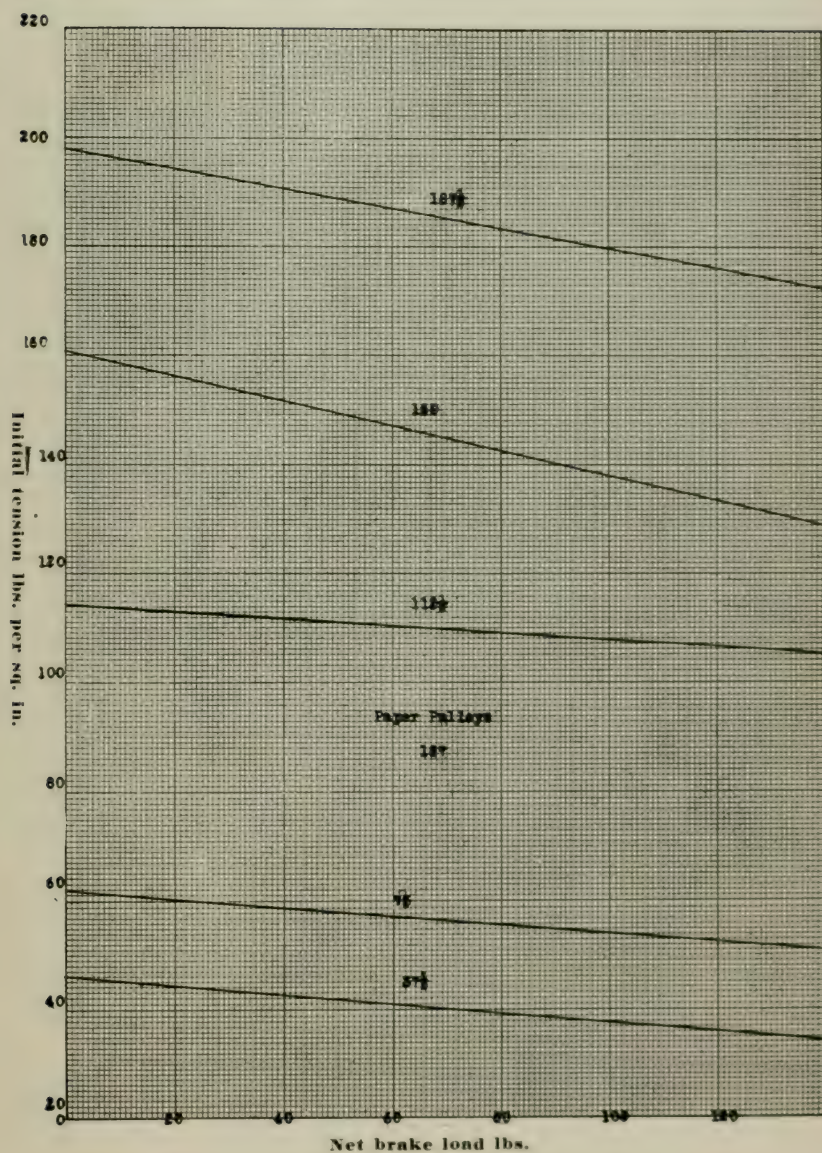
Net Brake Load	Revolutions	Light Flickers	Net Tension Running	Arc of Contact	Initial Tension	% Slip Correctd for diffe- rence in Diam.	% Slip Curve
5	330	3	289.5	183	333.5	0.21	0.17
20	367	4	292.5	183		0.39	0.32
40	364	5	298.5	184		0.67	0.66
60	356	6	311.5	184		0.99	0.99
80	395	8	326.5	185		1.32	1.32
100	350	9	358.5	187	286.5	1.87	1.87
5	438	4	368.5	181	408	0.21	0.17
20	373	4	371.5	181		0.37	0.30
40	454	6	376.5	183		0.62	0.62
60	439	7	383.5	184		0.89	0.91
80	367	7	393.5	185		1.21	1.20
100	360	8	405.5	186		1.52	1.52
110	328	8	411.5	186	367	1.74	1.74

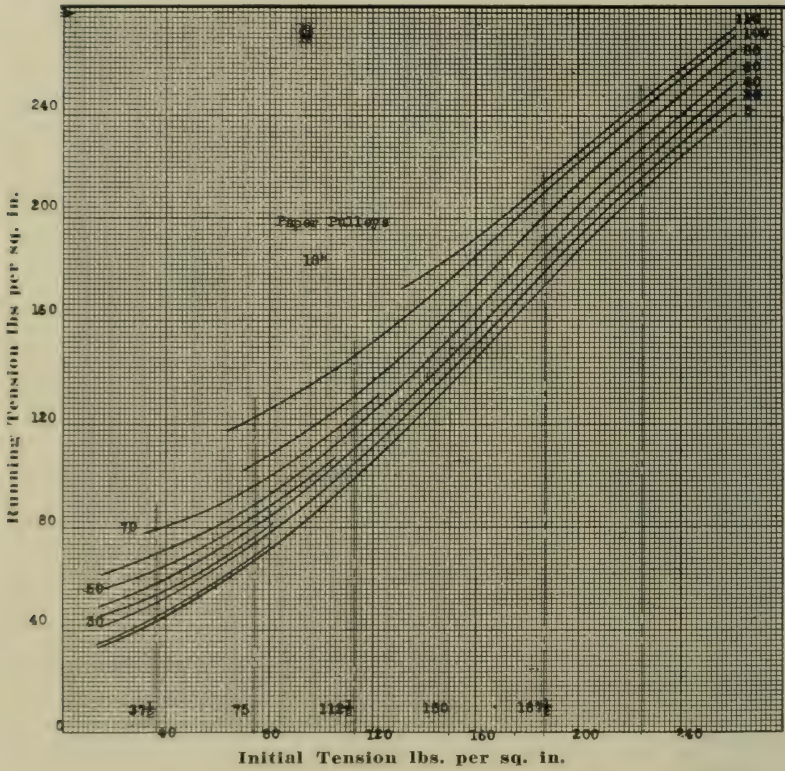
PAPER PULLEYS

Net Brake Load	Tension per sq. in. belt section		Tension Per Sq. In. Curve	T ₁ —T ₂	T ₁ +T ₂	T ₁	T ₂	$\frac{T_1}{T_2}$	Arc of Contact Degrees	% Slip Curve	Coefficient of Friction
	Initial	Observed									
Initial Tension — 37½ lbs. per sq. in. belt section											
5	45.3	42.0	44.0	13.3	79.2	46.2	33.0	1.40	185.0	0.21	0.104
12	44.8	43.0	44.5	32.0	80.1	56.1	24.0	2.34	186.0	0.44	0.262
20	44.0	46.0	51.0	53.4	91.8	72.6	19.2	3.90	187.0	0.80	0.417
30	43.1	48.0	54.0	80.0	97.4	88.6	8.6	10.30	188.5	1.25	0.706
Initial Tension — 75 lbs. per sq. in. belt section											
5	61.6	56.0	68.0	13.3	122.3	67.8	54.5	1.24	183.8	0.19	0.065
12	60.9	57.0	69.5	32.0	125.1	78.5	46.5	1.69	184.5	0.25	0.163
20	60.1	61.0	75.3	53.4	135.5	94.5	41.1	2.30	185.2	0.40	0.257
30	59.3	62.0	77.7	80.0	140.0	110.0	29.9	3.68	186.3	0.61	0.401
40	58.7	65.0	80.5	106.8	145.0	125.9	19.1	6.59	187.5	0.88	0.576
50	57.8	72.0	84.0	133.5	151.2	142.4	8.8	16.20	189.0	1.12	0.844
Initial Tension — 112½ lbs. per sq. in. belt section											
5	114.4	100.0	100.0	13.3	180.0	96.7	83.4	1.16	183.5	0.17	0.046
20	113.3	100.3	104.5	53.4	188.0	120.7	67.2	1.79	183.8	0.35	0.182
40	112.0	103.0	111.0	106.8	200.0	153.3	46.7	3.29	184.8	0.74	0.370
60	110.6	113.2	118.5	160.2	213.0	186.6	26.5	7.02	186.2	1.10	0.600
70	110.6	120.0	124.0	186.9	223.2	205.0	18.2	11.26	187.0	1.30	0.737
80	109.1	126.0	133.0	213.6	240.0	226.6	13.0	17.40	188.0	1.55	0.872

PAPER PULLEYS

Net Brake Load	Tension per sq. in. belt section		Tension Per Sq. In. Curve	T ₁ -T ₂		T ₁ +T ₂	T ₁	T ₂	$\frac{T_1}{T_2}$	Arc of Contact Degrees	% Slip Curve	Coefficient of Friction
	Initial	Observed										
	Initial Tension — 150 lbs. per sq. in. belt section											
5	159.5	145.5	135.5	13.3	244.0	128.7	115.3	1.11	182.7	0.16	0.03	
20	156.0	147.2	141.0	53.4	253.8	152.3	101.5	1.50	183.0	0.32	0.13	
40	151.5	150.2	146.0	106.8	262.5	184.5	78.0	2.37	183.8	0.67	0.27	
60	147.0	156.7	154.0	160.2	277.2	218.7	58.5	3.72	185.0	0.98	0.41	
80	142.6	164.3	163.0	213.6	293.0	253.0	40.0	6.33	186.1	1.35	0.57	
100	138.3	180.5	175.5	267.0	316.0	291.5	24.5	11.90	187.4	1.76	0.76	
Initial Tension — 187½ lbs. per sq. in. belt section												
5	197.0	185.5	174.0	13.3	313.0	163.2	149.8	1.09	181.6	0.16	0.03	
20	194.2	187.0	179.5	53.4	323.0	188.2	134.8	1.40	182.0	0.30	0.11	
40	191.7	189.5	185.0	106.8	333.0	220.0	113.0	1.95	182.6	0.60	0.21	
60	187.0	193.0	193.0	160.2	347.0	253.6	93.4	2.72	183.8	0.87	0.32	
80	183.0	198.0	201.0	213.6	362.0	288.0	74.0	3.89	185.0	1.18	0.42	
100	179.7	204.0	210.0	267.0	378.0	323.0	55.0	5.88	186.2	1.45	0.55	
110	178.0	207.0	215.0	293.7	387.0	310.5	46.5	7.32	186.8	1.65	0.61	





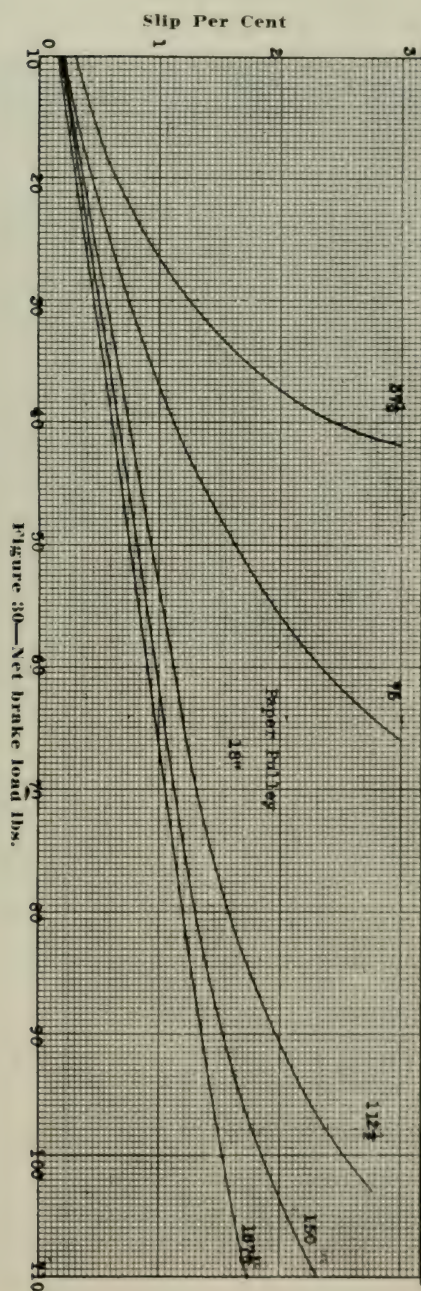


FIGURE 30—Net brake load lbs.

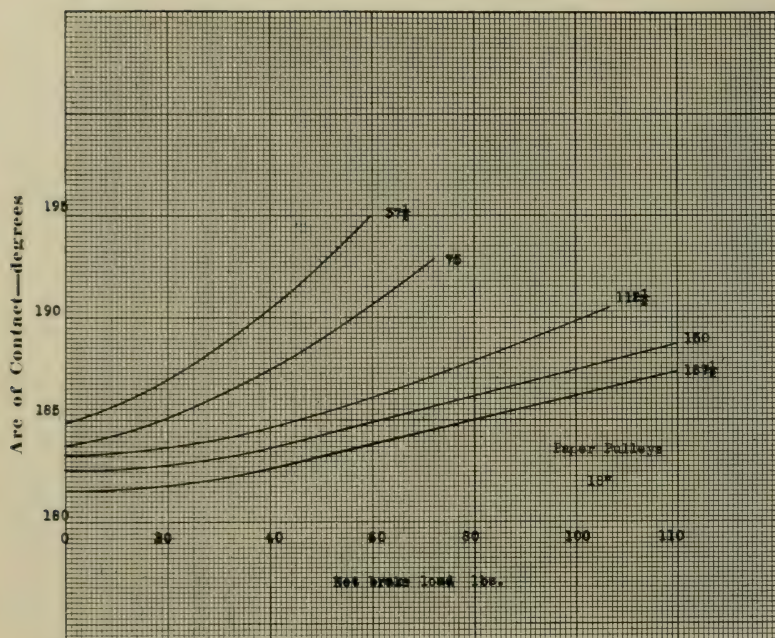
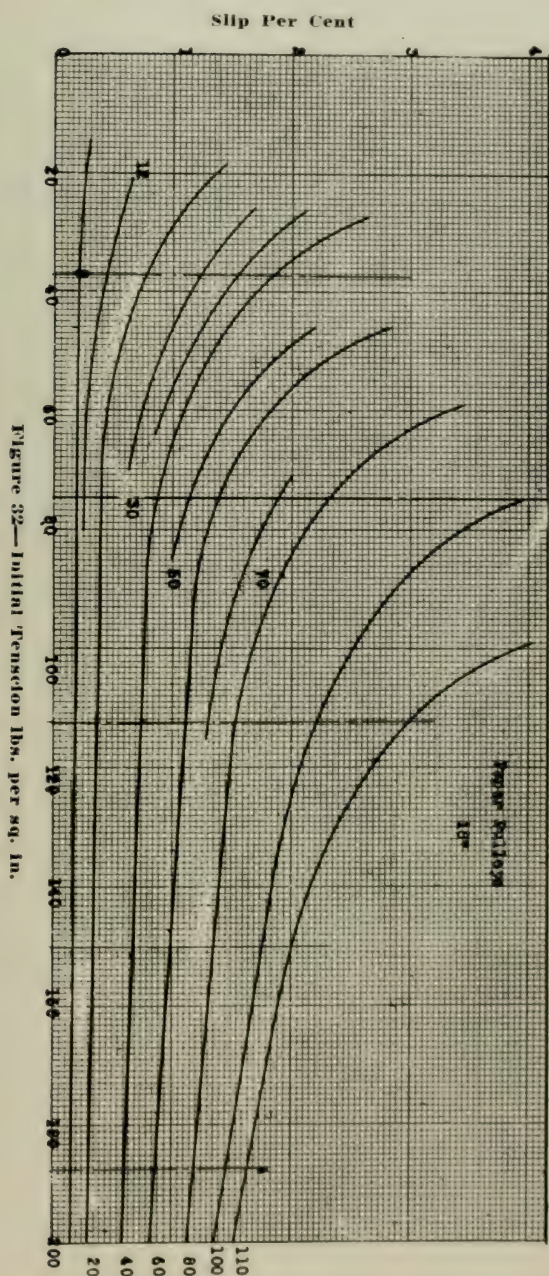


Figure 31—Net brake load lbs.



WOOD PULLEYS

SPLIT

Dia. Driver 18½

Dia Follower 18½

Net Brake Load	Revolutions	Flickers	Net Tension Running	Arc of Contact	Initial Tension	Slip %	Slip Curve
5	226	1	80	185	98	0.42	0.47
10	352	2	81	185		0.57	0.57
20	381	3	93	186		0.78	0.78
30	318	4	112	188		1.26	1.23
40	345	8	132	190	92.5	2.32	2.27
5	232	1	140	184	162.5	0.43	0.40
10	385	2	141	184		0.52	0.50
20	433	3	144	185		0.69	0.66
40	371	4	160	186		1.08	1.08
60	390	8	194	189	144.2	2.05	2.05
5	370	1	206	184	232.5	0.27	0.30
20	412	2	206	184		0.49	0.49
40	368	3	209	185		0.82	0.82
60	343	4	230	187		1.17	1.17
80	409	8	252	189	215.0	1.95	1.90

WOOD PULLEYS

SPLIT

Net Brake Load	Revolutions	Flickers	Net Tension Running	Arc of Contact	Initial Tension	Slip %	Slip Curve
5	374	1	281	183	311	0.27	0.25
20	225	1	279	183		0.44	0.44
40	420	3	281	184		0.71	0.73
60	391	4	286	185		1.02	1.02
80	381	5	305	187		1.31	1.31
100	310	7	323	188	287	2.26	2.14
5	398	1	373	182	400	0.25	0.25
20	250	1	370	182		0.40	0.38
40	322	2	370	183		0.62	0.62
60	456	4	373	184		0.87	0.87
80	444	5	379	185		1.12	1.12
100	370	6	386	187	364.0	1.62	1.51
110	334	6	391	188		1.80	1.83

WOOD PULLEYS
SPLIT

Net Brake Load	Tension per sq. in. belt section Initial Observed	Tension Per Sq. In. Curve	$T_1 - T_2$	$T_1 + T_2$	T_1	T_2	$\frac{T_1}{T_2}$	Arc of Contact Degrees	% Slip Curve	Coefficient of Friction
		Initial	Tension	— 37½ lbs. per sq. in. belt section						
5	49.3	40.2	13.2	62.1	37.6	24.4	1.54	184.8	0.50	0.13
10	49.1	40.8	26.4	68.4	47.4	21.0	2.25	185.1	0.65	0.25
20	48.5	46.7	52.8	79.2	66.0	13.2	5.00	186.2	0.97	0.49
30	48.0	56.4	79.2	93.6	86.4	7.2	12.00	187.8	1.50	0.76
40	47.2	66.4	105.6	113.4	109.5	3.9	28.10	190.0	2.95	1.00
		Initial	Tension	— 75 lbs. per sq. in. belt section						
5	81.6	70.5	13.2	115.2	64.2	51.0	1.25	184.0	0.40	0.07
10	81.2	71.0	26.4	120.6	73.5	47.1	1.56	184.1	0.49	0.14
20	80.0	72.4	52.8	126.5	89.6	36.9	2.43	184.6	0.65	0.27
40	78.0	80.5	105.6	141.3	123.4	17.9	6.90	186.3	1.25	0.59
60	76.0	97.6	158.4	176.4	167.4	9.0	18.60	189.0	2.10	0.89
		Initial	Tension	— 112½ lbs. per sq. in. belt section						
5	117.2	103.7	13.2	176.4	94.8	81.6	1.16	183.4	0.33	0.05
20	115.5	103.7	52.8	180.0	116.4	63.6	1.83	184.0	0.55	0.18
40	113.6	109.8	105.6	190.8	148.2	42.6	3.48	185.1	0.83	0.38
60	111.8	115.8	158.4	210.6	184.5	26.1	7.06	186.8	1.16	0.60
80	109.8	126.8	211.2	232.2	221.7	10.5	21.10	189.0	1.85	0.92

WOOD PULLEYS
SPLIT

Net Brake Load	Tension per sq. in. belt section		Tension Per Sq. In. Curve	$T_1 - T_2$	$T_1 + T_2$	T_1	T_2	$\frac{T_1}{T_2}$	Arc of Contact Degrees	% Slip Curve	Coefficient of Friction
	Initial	Observed									
	Initial Tension — 150 lbs. per sq. in. belt section										
5	156.0	141.5	136.0	13.2	244.8	129.0	115.8	1.11	182.8	0.26	0.03
20	154.4	140.2	138.0	52.8	248.4	150.6	97.8	1.54	183.0	0.47	0.13
40	152.2	141.5	140.5	105.6	252.9	179.2	73.7	2.44	183.7	0.73	0.28
60	150.0	143.8	146.0	158.4	262.8	210.6	52.2	4.14	185.0	1.02	0.44
80	148.0	153.4	154.5	211.2	278.1	244.6	33.5	7.35	186.4	1.30	0.61
100	146.0	164.0	166.0	264.0	298.8	281.3	17.5	16.10	188.1	2.01	0.84
Initial Tension — 187½ lbs. per sq. in. belt section											
5	201.0	187.5	173.0	13.2	311.4	162.3	149.1	1.09	181.7	0.18	0.03
20	199.0	186.2	174.5	52.8	314.1	183.1	130.6	1.40	181.8	0.40	0.11
40	195.8	186.2	178.0	105.6	320.4	213.0	107.4	1.98	182.6	0.63	0.21
60	192.7	187.5	182.5	158.4	328.5	243.4	85.1	2.86	183.8	0.88	0.33
80	189.4	190.1	187.0	211.2	336.6	273.9	62.7	4.37	185.3	1.12	0.45
100	186.2	194.2	194.5	264.0	350.1	307.0	43.1	7.13	187.0	1.50	0.60
110	184.7	196.8	199.0	290.4	358.2	342.2	31.0	9.55	187.8	1.82	0.69

Initial Tension lbs. per sq. in.

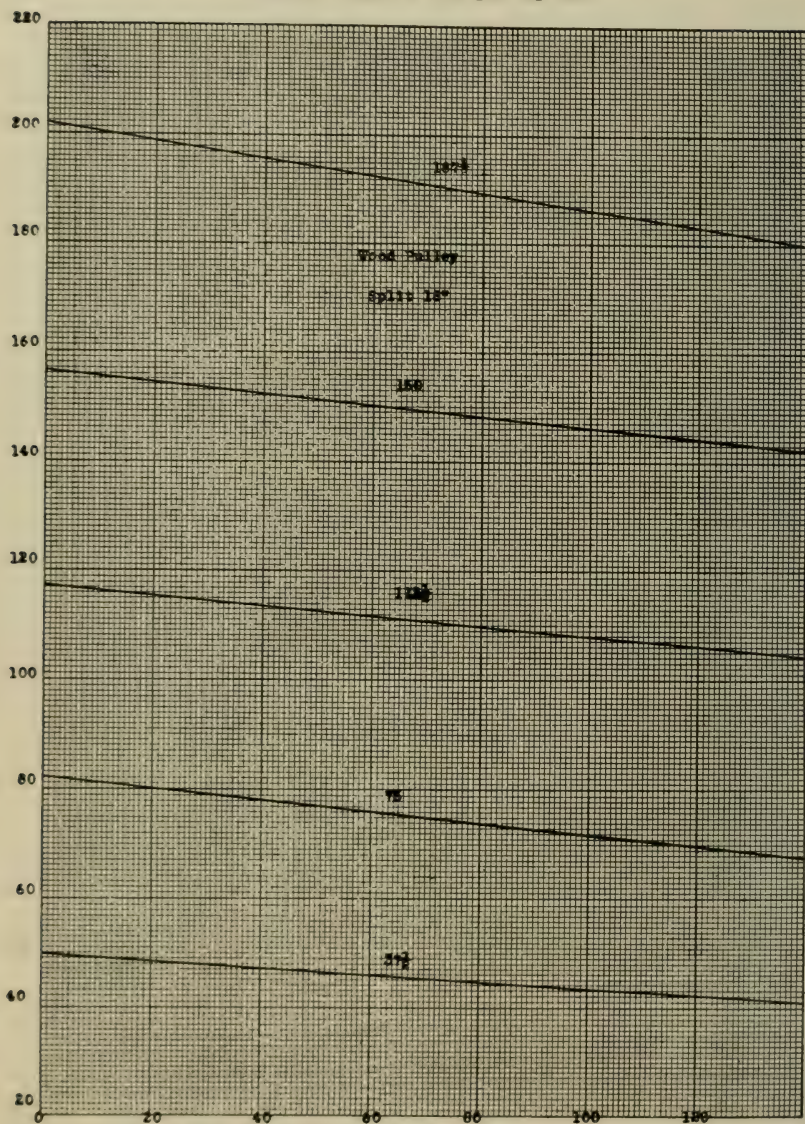
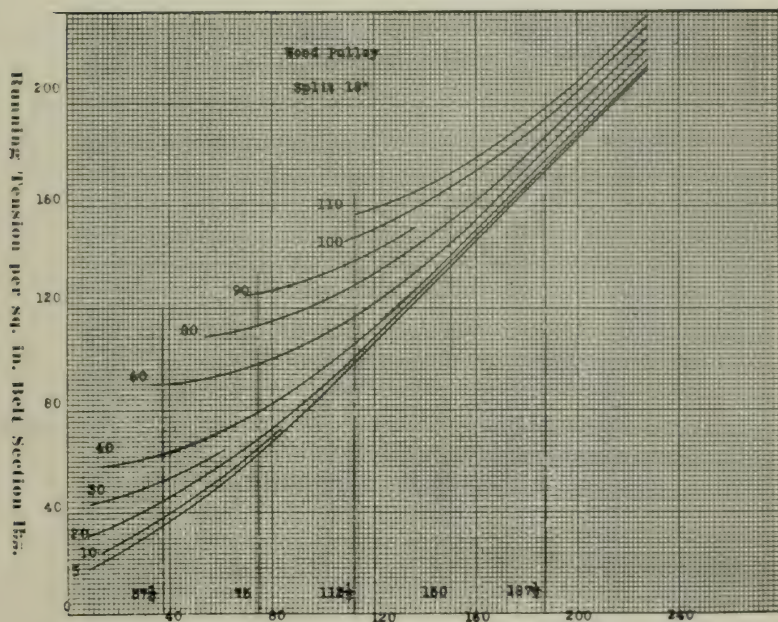


Figure 33—Initial Tension lbs. per sq. in.



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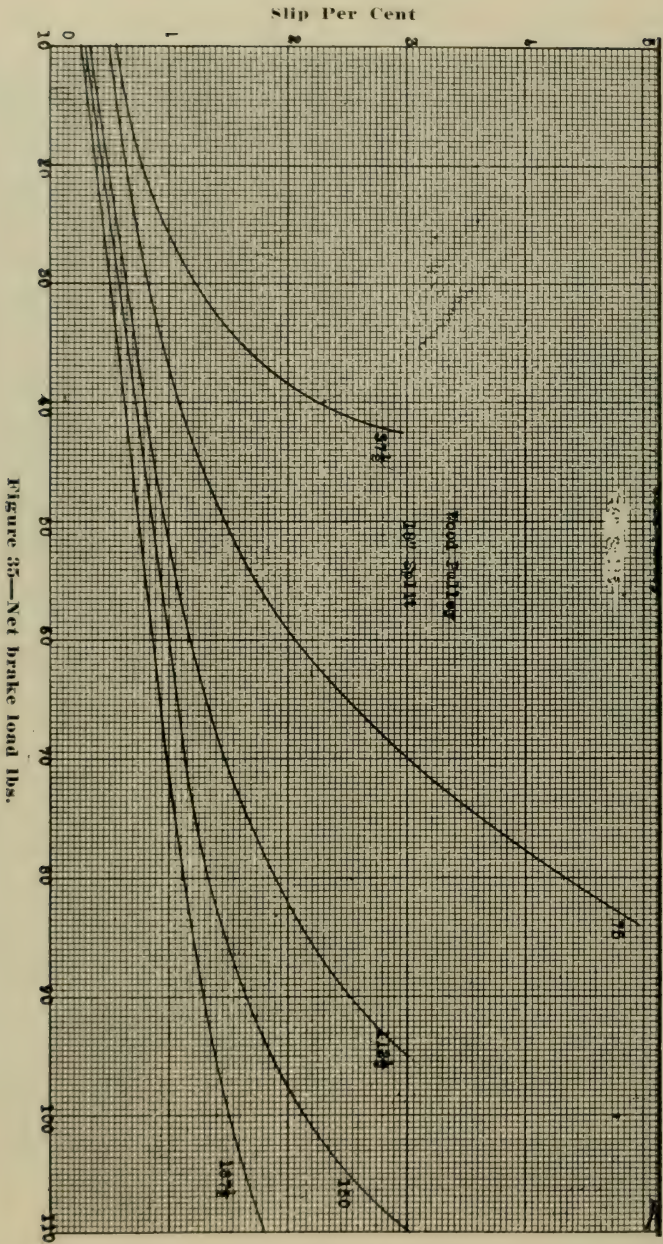


Figure 35—Net brake load lbs.

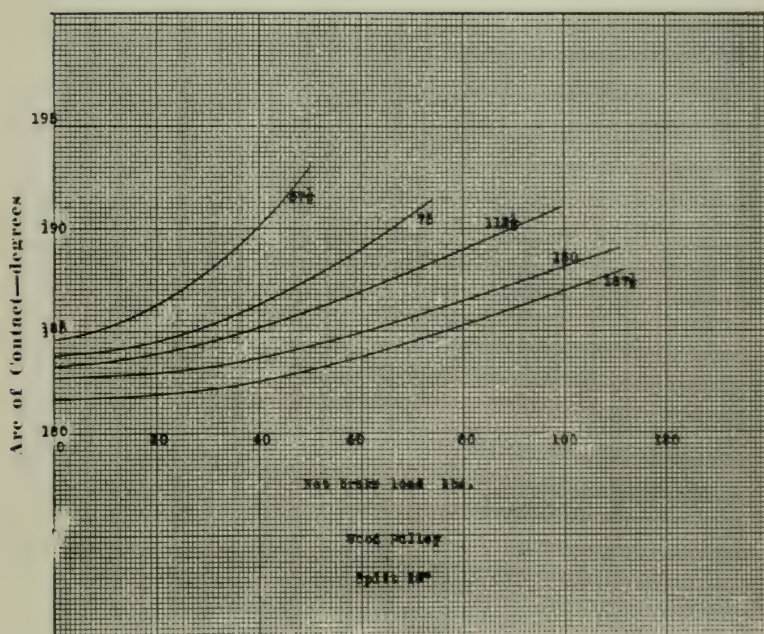
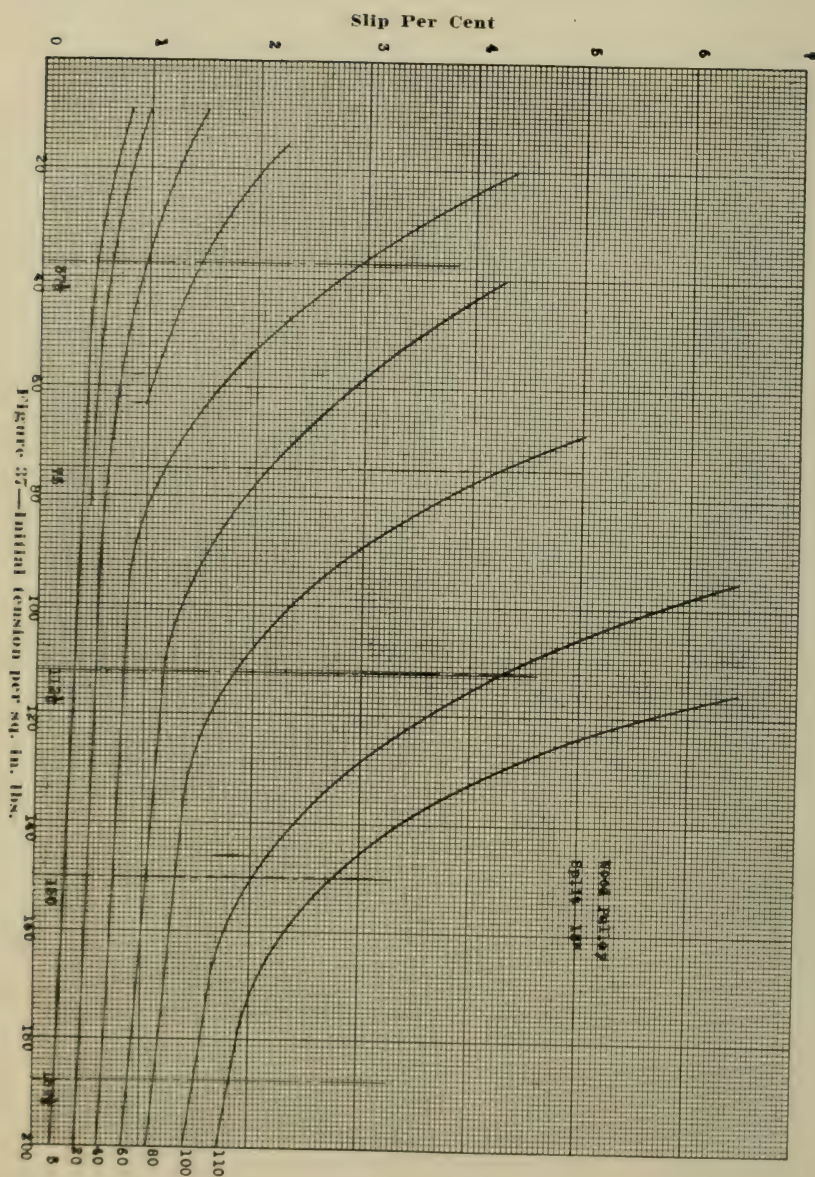


Figure 36—Net brake load lbs.



SPLIT STEEL PULLEYS

Dia. Driver 18¼

Dia Follower 18¼

Net Brake Load	Revolutions	Flickers	Net Tension Running	Arc of Contact	Initial Tension	Slip %	Slip Curve
5	751	1	85	185	101.5	0.13	0.25
10	422	1	86	185		0.37	0.30
20	428	2	96	186		0.47	0.47
30	395	3	112	188		0.76	0.76
40	385	5	128	190	101	1.30	1.30
5	785	1	130	184	156	0.12	0.15
10	472	1	130	184		0.21	0.21
20	506	2	133	185		0.40	0.40
40	471	4	148	186	144	0.85	0.86
5	817	1	216	184	244.5	0.12	0.15
20	296	1	210	184		0.34	0.30
40	310	2	215	185		0.64	0.63
60	242	3	224	187		1.24	1.24
80	285	8	246	188	225	2.81	2.65

SPLIT STEEL PULLEYS

Net Brake Load	Revolutions	Flickers	Net Tension Running	Arc of Contact	Initial Tension	Slip %	Slip Curve
5	886	1	296	183	329	0.11	0.10
20	354	1	290	183		0.28	0.26
40	362	2	286	184		0.55	0.53
60	476	4	292	185		0.84	0.82
80	342	4	305	186		1.17	1.26
100	370	9	324	187	305	2.43	2.34
5	986	1	360	182	398.5	0.10	0.07
20	372	1	355	182		0.27	0.24
40	412	2	350	183		0.48	0.55
60	395	3	353	184		0.76	0.75
80	299	3	360	185		1.00	1.03
100	312	5	374	186		1.60	1.67
110	214	5	378	187	374.5	2.34	2.25

SPLIT STEEL PULLEYS

Net Brake Load	Tension per sq. in. belt section Initial	Tension per Sq. In. Curve Observed	T ₁ -T ₂	T ₁ +T ₂	T ₁	T ₂	$\frac{T_1}{T_2}$	Arc of Contact Degrees	$\frac{c}{r}$ Slip Curve	Coefficient of Friction
			Initial Tension — 37½ lbs. per sq. in. belt section							
5	51.1	42.7	13.1	63.0	38.0	24.9	1.52	184.7	0.32	0.13
10	51.1	43.3	26.2	70.2	48.2	22.0	2.19	185.0	0.40	0.24
20	51.0	48.2	52.4	75.6	64.0	11.6	5.51	186.2	0.61	0.52
30	51.0	56.4	78.6	90.0	84.1	5.6	15.08	187.7	1.05	0.82
40	51.0	64.5	104.8	112.5	108.6	3.9	27.85	189.9	1.80	1.00
			Initial Tension — 75 lbs. per sq. in. belt section							
5	78.5	65.5	13.1	108.0	60.5	47.5	1.27	183.9	0.15	0.09
10	78.2	65.5	26.2	112.5	69.3	43.2	1.61	184.0	0.20	0.15
20	77.6	67.0	52.4	116.1	84.2	31.9	2.64	184.5	0.37	0.30
40	78.2	74.5	104.8	135.9	120.3	15.6	7.71	186.0	0.87	0.63
			Initial Tension — 112½ lbs. per sq. in. belt section							
5	123.2	108.7	13.1	165.6	89.3	76.3	1.17	183.7	0.12	0.05
20	122.0	105.6	52.4	170.1	111.2	58.9	1.89	184.0	0.32	0.20
40	120.0	108.2	104.8	182.7	113.7	39.0	3.68	184.9	0.62	0.40
60	117.8	112.7	157.2	197.1	177.1	20.0	8.85	186.5	1.16	0.67
80	115.5	123.6	209.6	219.6	214.7	5.0	42.94	188.5	2.62	1.14

SPLIT STEEL PULLEYS

Net Brake Load	Tension per sq. in. belt section		Tension Per Sq. In. Curve	T ₁ —T ₂	T ₁ +T ₂	T ₁	T ₂	T ₁ — T ₂	Arc of Contact Degrees	ε% Slip Curve	Coefficient of Friction
	Initial	Observed									
Initial Tension — 150 lbs. per sq. in. belt section											
5	165.5	148.8	129.0	13.1	232.2	122.6	109.6	1.12	183.0	0.11	0.03
20	164.0	145.8	131.0	52.4	235.8	114.1	91.7	1.57	183.2	0.30	0.14
40	161.8	143.8	134.0	104.8	241.2	173.0	68.2	2.54	184.0	0.57	0.29
60	160.0	146.8	138.0	157.2	248.4	202.8	45.6	4.45	185.0	0.87	0.46
80	158.0	153.3	147.0	209.6	264.6	237.1	27.5	8.60	186.1	1.40	0.66
100	155.7	163.0	160.0	262.0	288.0	275.0	13.0	21.15	187.2	2.55	0.93
Initial Tension — 187½ lbs. per sq. in. belt section											
5	200.5	182.0	165.0	13.1	297.0	155.0	142.0	1.09	182.0	0.07	0.03
20	199.0	178.5	167.0	52.4	300.6	176.5	124.1	1.42	182.3	0.25	0.11
40	197.0	176.0	169.5	104.8	305.1	204.9	100.2	2.05	183.0	0.52	0.22
60	194.7	177.5	172.0	157.2	309.6	233.4	76.2	3.06	184.0	0.76	0.35
80	192.6	182.0	177.0	209.6	318.6	264.1	54.5	4.85	185.0	1.03	0.49
100	190.3	188.0	184.5	262.0	332.1	297.0	35.1	8.46	186.0	1.67	0.66
110	189.2	190.9	189.5	288.2	341.1	314.6	26.5	11.87	186.6	2.27	0.76

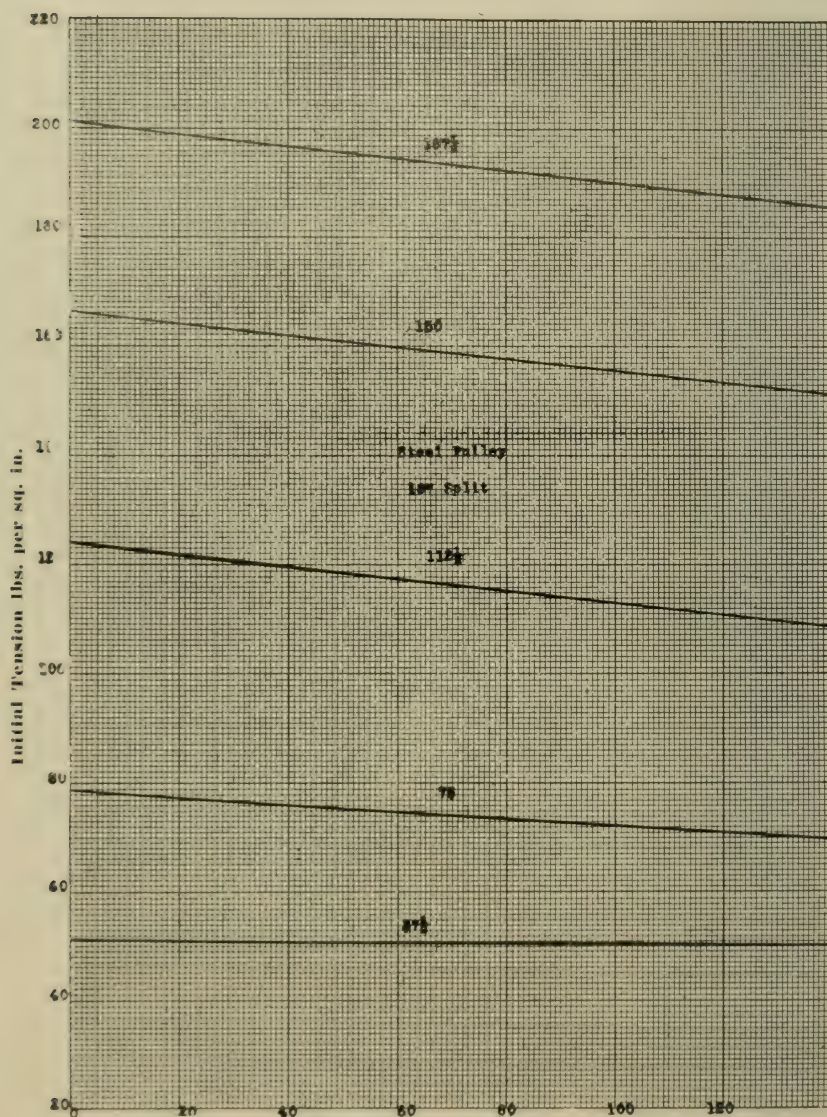


Figure 38—Net brake load lbs.

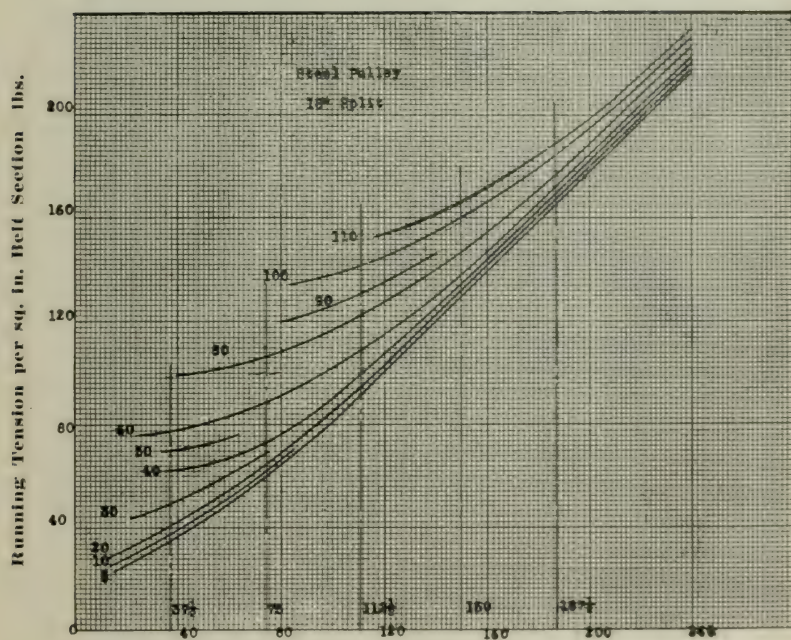


Figure 39—Initial tension per sq. in. Belt Section lbs.

Slip Per Cent

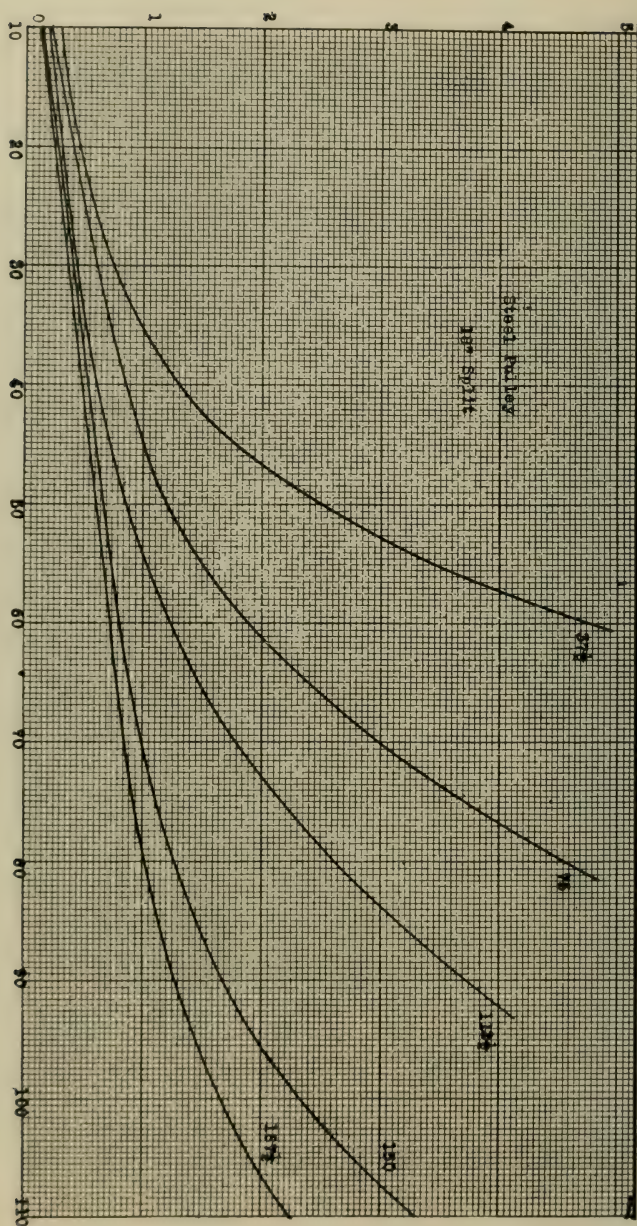


Figure 40—Net Brake Load lbs.

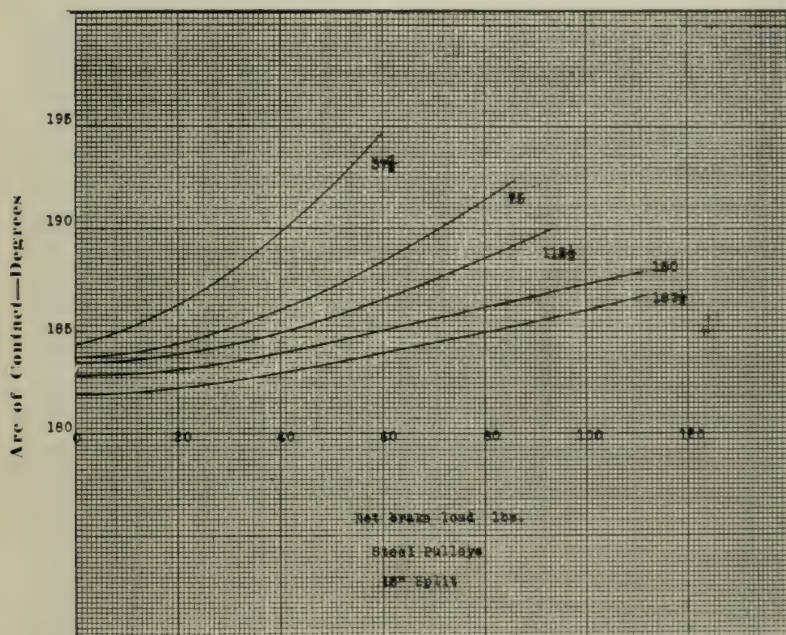
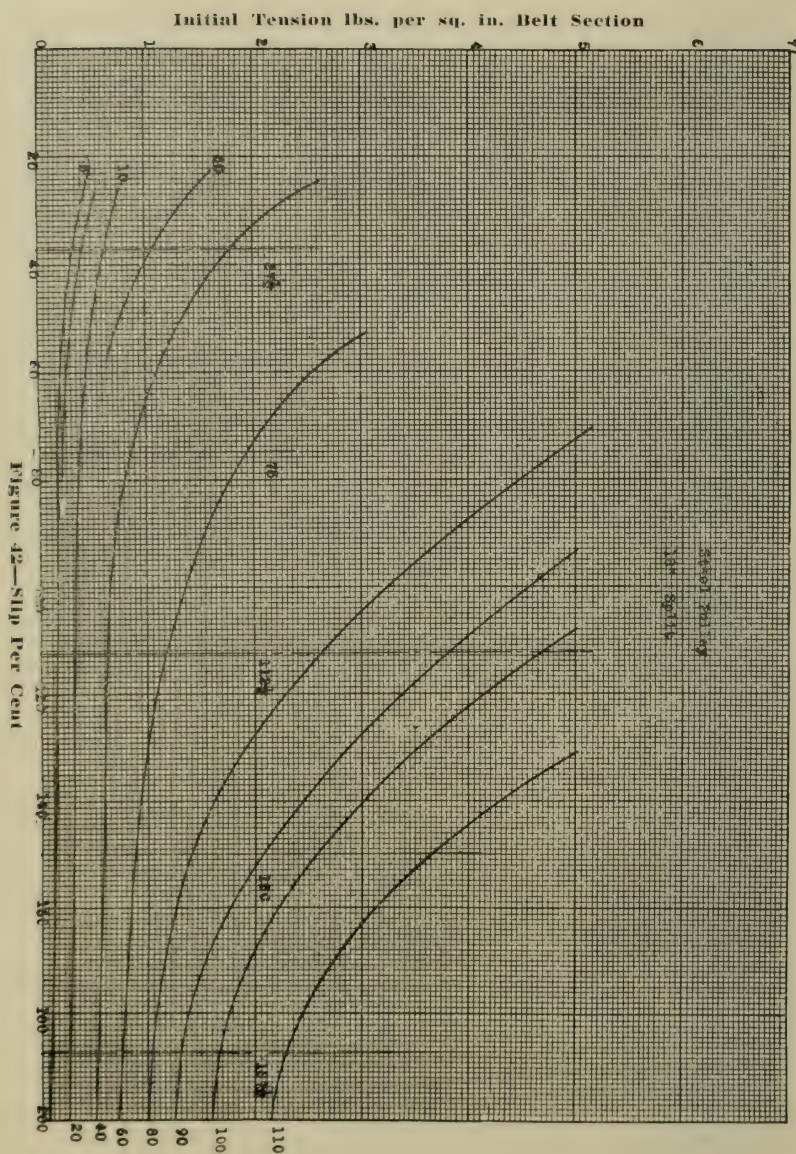


Figure 41—Net brake load lbs.



CAST IRON PULLEYS

Dia. Driver 18 $\frac{1}{2}$ Dia. Follower 18 $\frac{1}{2}$

Net Load Brake	Revolutions	Light Flickers	Net Running Tension	Arc Contact of	Initial Tension	Slip %	Slip Curve
5	673	1	75	185	93	0.15	0.15
10	403	2	77	185		0.50	0.50
20	237	3	97	186		1.27	1.27
35	134	4	137	189	88	2.98	3.00
10	267	1	120	184	153	0.37	0.37
20	362	2	125	185		0.55	0.55
40	234	4	163	186		1.71	1.76
50	185	4	189	188	139	2.60	2.77
10	326	1	200	184	248	0.31	0.31
20	393	2	200	184		0.51	0.51
40	264	3	211	185		1.14	1.05
60	257	5	244	187		1.95	1.98
70	177	5	258	188	234	2.82	2.80

CAST IRON PULLEYS

Net Load Brake	Revolutions	Light Flickers	Net Tension Running	Arc of Contact	Initial Tension	Slip %	Slip Curve
10	371	1	253	183	288	0.27	0.27
20	222	1	248	183		0.45	0.45
40	218	2	255	184		0.92	0.88
60	292	4	269	185		1.37	1.47
80	234	6	300	186	272	2.56	2.60
10	376	1	365	182	416	0.27	0.27
20	253	1	367	182		0.40	0.40
40	279	2	367	183		0.72	0.68
60	376	4	371	184		1.06	1.00
80	138	2	385	185		1.45	1.46
100	162	4	401	186		2.47	2.50
110	77	3	417	187	372	3.90	3.85

CAST IRON PULLEYS

Net Brake power	Tension per sq. in. belt section Initial Observed	Tension per Sq. In. Curve	$T_1 - T_2$	$T_1 + T_2$	T_1	T_2	$\frac{T_1}{T_2}$	Arc of Contact Degrees	% Slip Curve	Coefficient of Friction
		Initial Tension — 37½ lbs. per sq. in. belt section								
5	46.7	37.8	13.2	55.8	34.5	21.3	1.62	184.7	0.20	0.15
10	46.2	38.8	26.4	61.2	43.8	17.4	2.52	185.0	0.57	0.28
20	45.8	48.8	52.8	82.8	67.8	15.0	4.52	186.1	1.30	0.46
35	45.0	69.0	92.4	124.2	108.3	15.9	6.82	189.0	3.45	0.58
		Initial Tension — 75 lbs. per sq. in. belt section								
10	76.2	60.4	26.4	102.6	64.5	38.1	1.69	184.0	0.35	0.16
20	75.0	62.9	52.8	113.4	83.1	30.3	2.71	184.6	0.72	0.31
40	72.5	82.0	105.6	148.5	127.1	21.4	5.94	186.3	1.70	0.55
50	71.3	95.1	122.0	180.9	156.5	24.4	6.41	187.7	2.55	0.57
		Initial Tension — 112½ lbs. per sq. in. belt section								
10	124.5	100.6	26.4	156.6	91.5	65.1	1.40	183.6	0.32	0.10
20	123.3	100.6	52.8	165.6	109.2	56.4	1.94	184.0	0.52	0.21
40	121.2	106.0	105.6	181.8	143.7	38.1	3.77	185.0	1.10	0.41
60	119.5	122.8	158.4	216.0	187.2	28.8	6.50	186.8	2.10	0.57
70	118.3	129.8	184.8	230.4	207.6	22.8	9.10	188.1	3.00	0.67

CAST IRON PULLEYS

Net Brake Load	Tension per sq. in. belt section		Tension Per Sq. In. Curve	Tension — 150 lbs. per sq. in. belt section			$\frac{T_1}{T_2}$	Arc of Contact Degrees	$\frac{\%}{\text{Slip}}$ Curve	Coefficient of Friction
	Initial	Observed		$T_1 - T_2$	$T_1 + T_2$	T_1	T_2			
				Initial Tension — 150 lbs. per sq. in. belt section						
10	144.8	127.2	124.0	26.4	223.2	124.8	98.4	127	182.8	0.07
20	144.6	124.8	128.0	52.8	230.4	141.6	88.8	1.60	183.1	0.14
40	142.0	128.1	134.0	105.6	241.2	173.4	67.8	2.56	183.8	0.29
60	140.3	125.1	142.0	158.4	255.6	207.0	48.6	4.26	184.6	0.45
80	139.0	150.9	158.0	211.0	284.4	247.8	36.6	6.76	186.2	0.59
				Initial Tension — 187½ lbs. per sq. in. belt section						
10	209.0	183.5	160.0	26.4	288.0	157.2	130.8	1.20	182.0	0.06
20	207.0	184.5	163.0	52.8	293.4	173.1	120.3	1.44	182.2	0.11
40	203.0	184.5	169.0	105.6	304.2	204.9	99.3	2.07	182.6	0.23
60	199.0	186.5	175.0	158.4	315.0	236.7	78.3	3.03	183.3	0.35
80	195.5	193.5	186.0	211.0	334.8	273.0	61.8	4.42	184.4	0.46
100	191.0	201.7	199.0	264.0	358.2	311.1	47.1	6.60	186.0	0.58
110	189.0	209.5	208.0	290.4	374.4	332.4	42.0	7.90	187.3	0.63

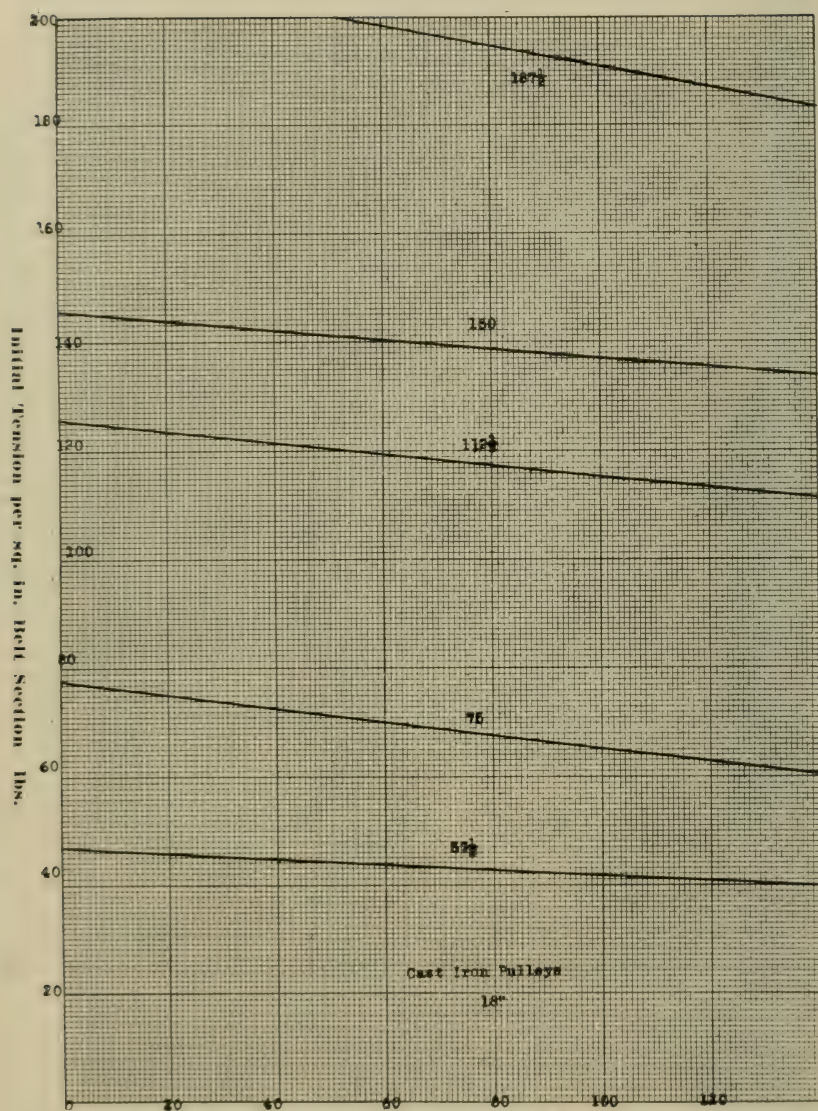


Figure 43—Net brake load lbs.

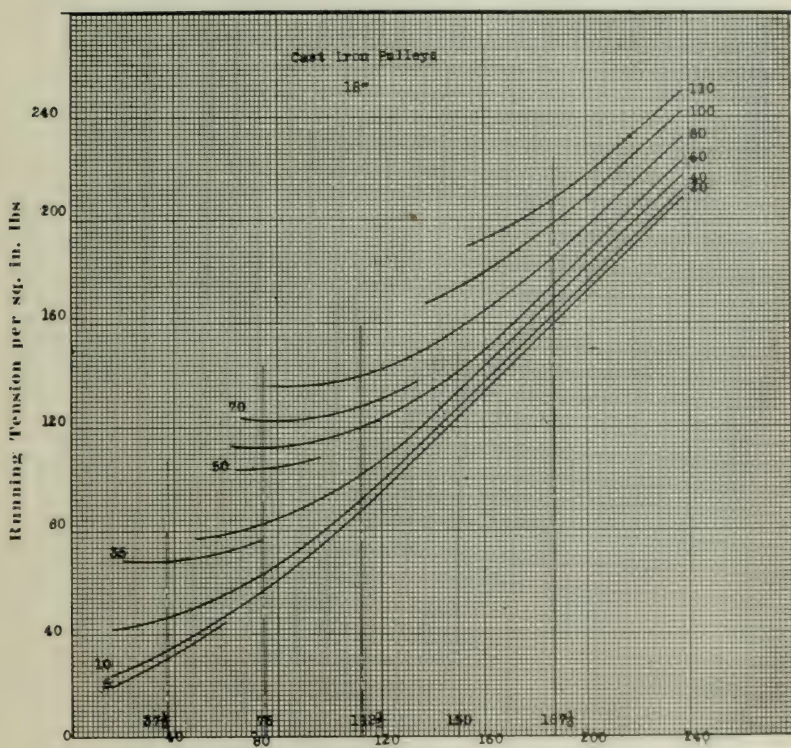


Figure 44—Initial tension lbs. per sq. in.

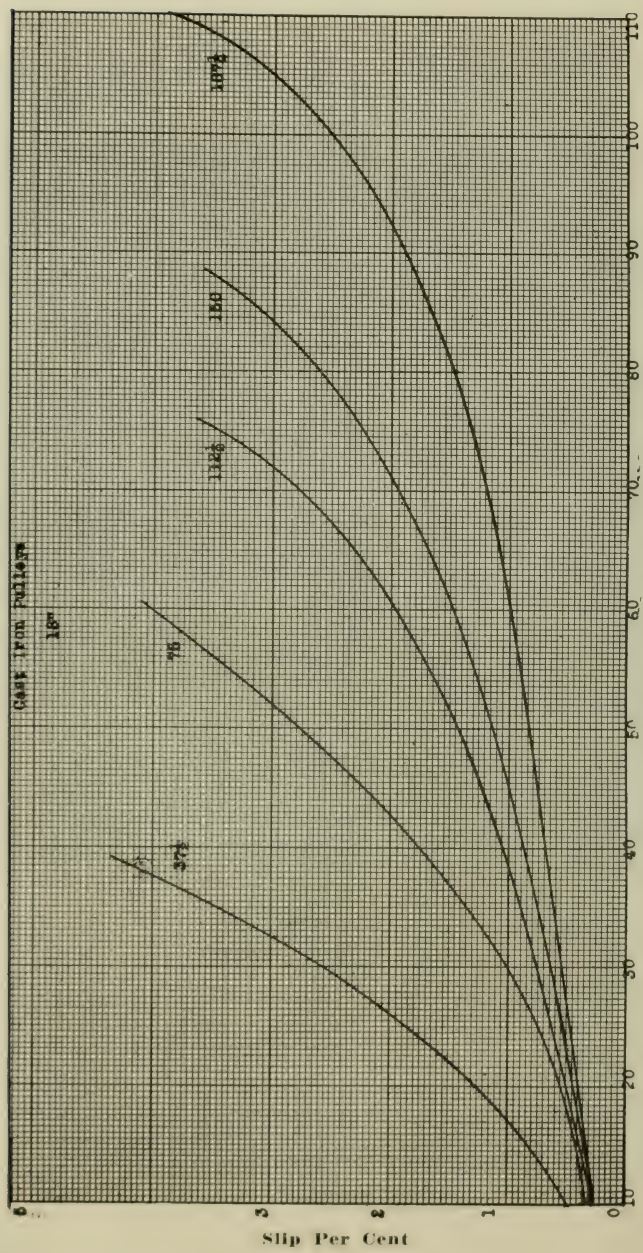


Figure 45.—Net brake load lbs.

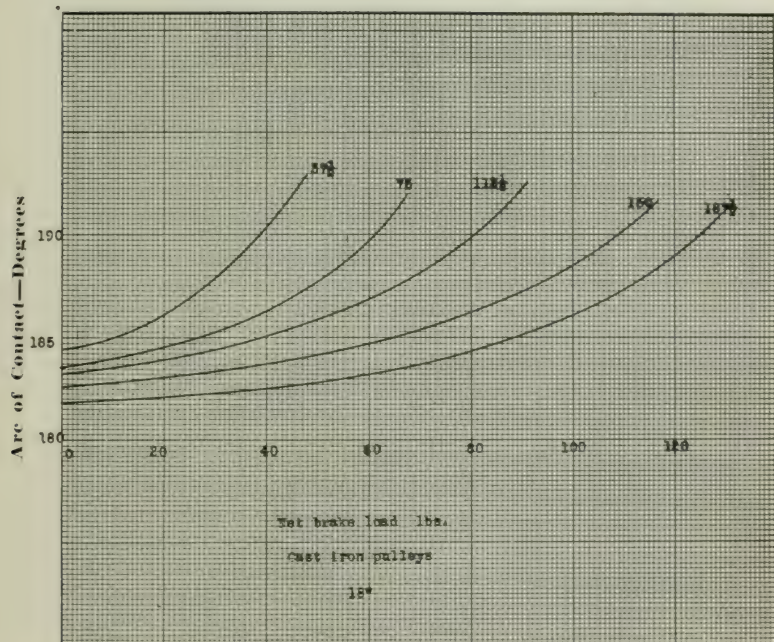


Figure 46—Net brake load lbs.

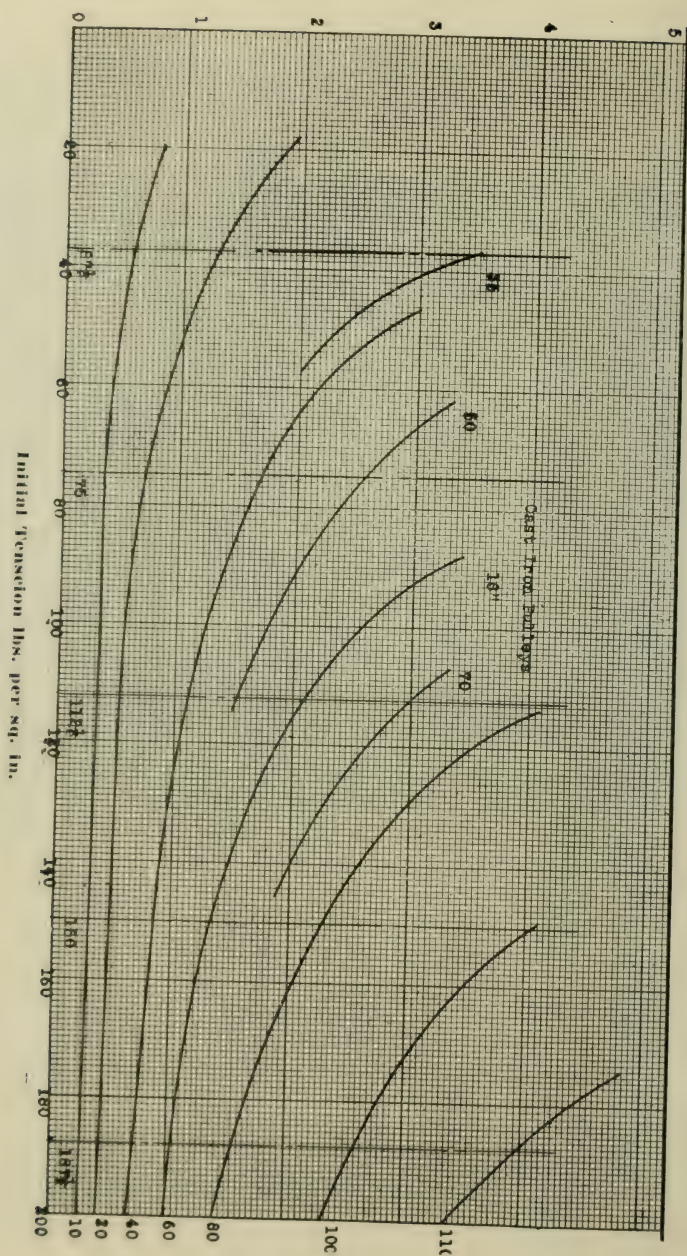
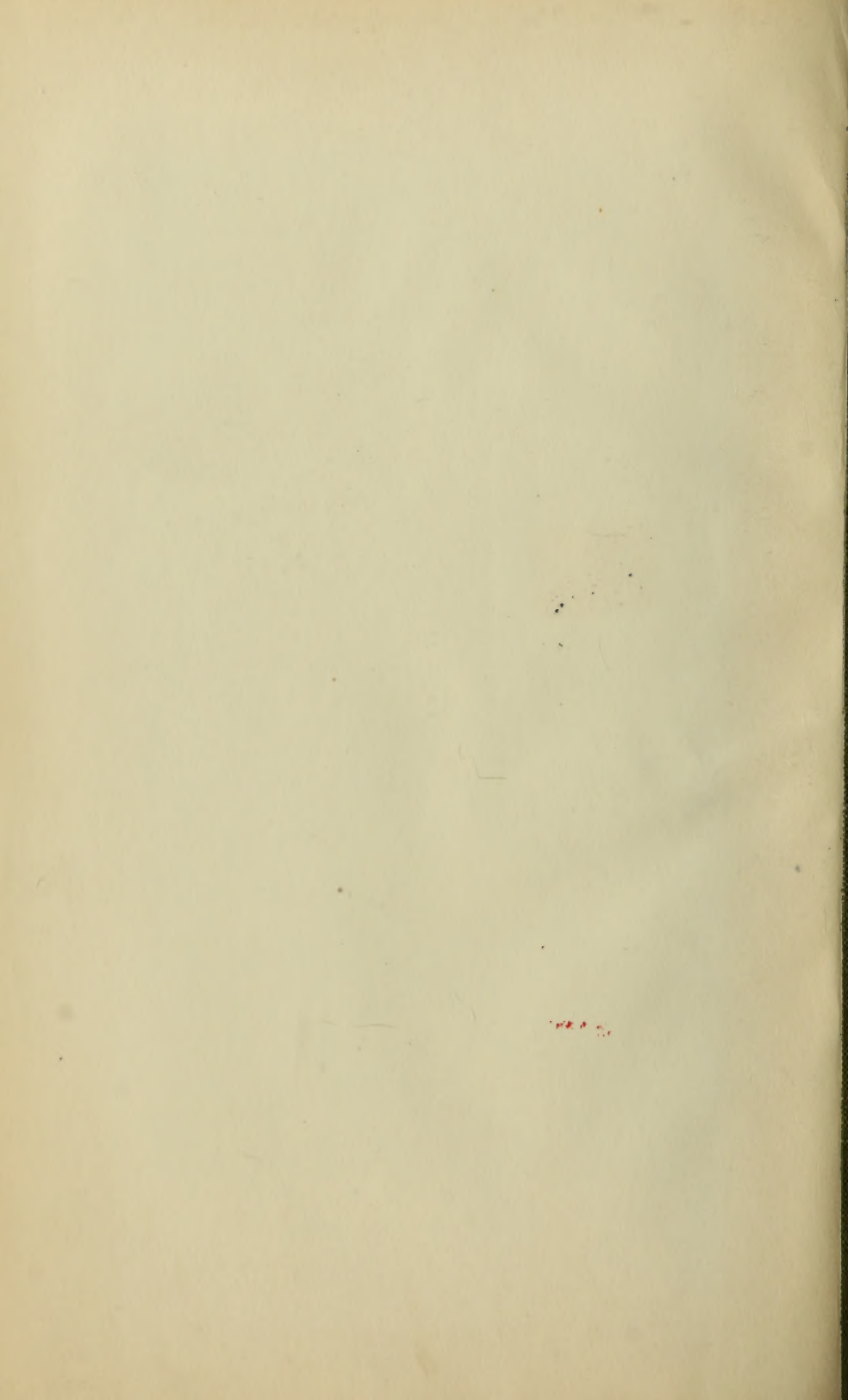


Figure 47—Slip Per Cent



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